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Requirements Document for the Redesign of the DIM-based Diagnostics Transport and Handling System at the National Ignition Facility (NIF)

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1. Executive Summary

The National Ignition Facility (NIF, Figure 1) is the world's leading user research facility for inertial confinement fusion. Diagnostic instruments that collect data from the experiment shots are transported around the facility using a series of disjointed, suboptimal transport and handling (T&H) subsystems that compromise user efficiency and ergonomics. Significant time savings and improvements to the diagnostic exchange process could be realized by designing a new transport and handling system that minimizes the hand-offs between T&H subsystems, reduces operator hassle and ergonomic strain, and improves the long-term maintainability of the system.

Figure 1 – View of NIF Laser Bay

In contrast to the current system – which employs several manually-operated carts and containers to transport the diagnostic, dock it to its destination, and install it – the new diagnostic transporter integrates the contamination container with the transport cart and provides a dynamic range of adjustability to interface with its destination. This single transporter has the requisite maneuverability, height adjustability, and fine adjustment capabilities without any rigging transactions to support contaminated diagnostic transport and handling at the alignment station and Equatorial and Polar DIMs. A remote-controlled user interface device allows operators a more hands-off experience that reduces ergonomic strain and improves safety. Assuming the cost is not prohibitive, diagnostic storage will be accomplished by simply stowing the transporter in its lowest position in the designated area of NIF. This concept for a new diagnostic transport and handling system would be better aligned with the core values of NIF: safety, quality, and reliability.

2. Mission Description

If simplified into three major subsystems (Figure 2), NIF is comprised of: the laser, the targets that implode during a “shot” (i.e. experiment), and the instruments that collect data during the shot. These instruments are termed “diagnostics” because they diagnose certain facets of the fusion experiments. Diagnostics can generically be classified further into “fixed-port” diagnostics and “insertable” diagnostics. Fixed-port diagnostics attach directly onto the NIF Target Chamber while insertable diagnostics are loaded into 6m-long, telescoping vacuum vessel systems called Positioners that insert, align, and operate them within the Chamber during a shot. The primary Positioner for diagnostics is called the Diagnostic Instrument Manipulator (DIM, Figure 3). There are three DIMs attached to the Target Chamber: two at the Equator (90-78 and 90-315) and one vertically on top of the Chamber (Polar DIM, PDIM, or DIM 0-0).

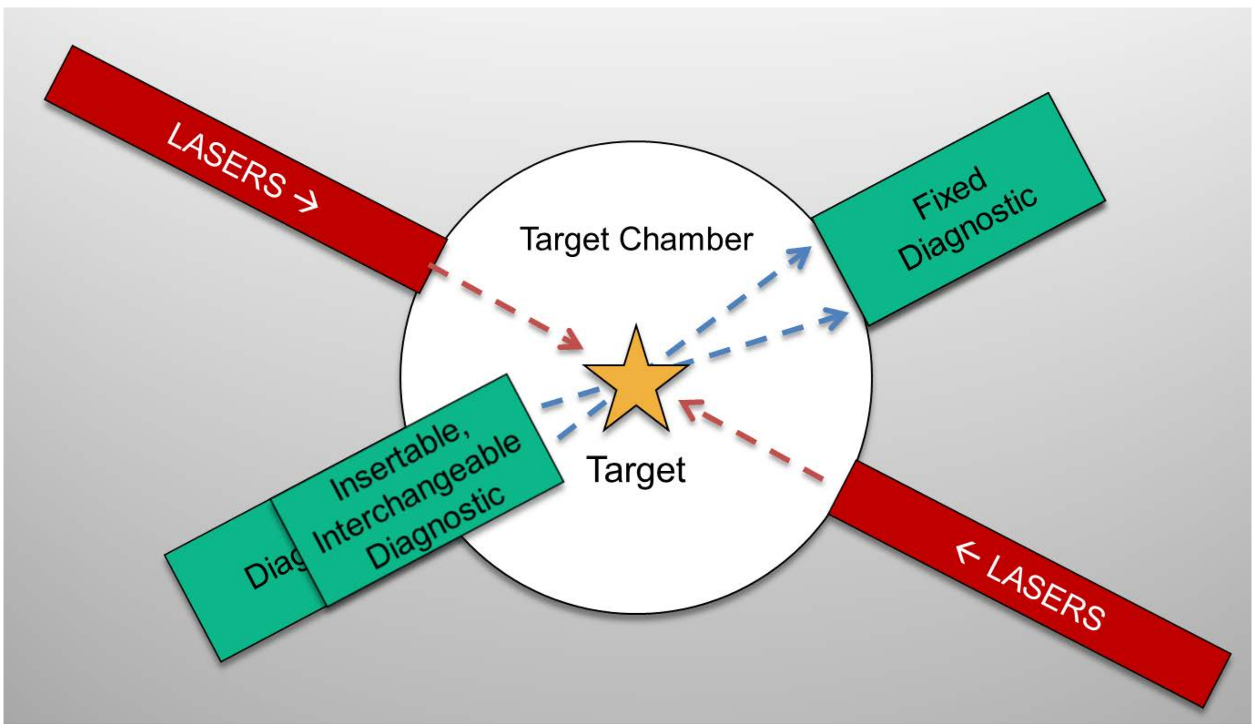

Figure 2 – Simplified Schematic of the Three Major Subsystems of NIF

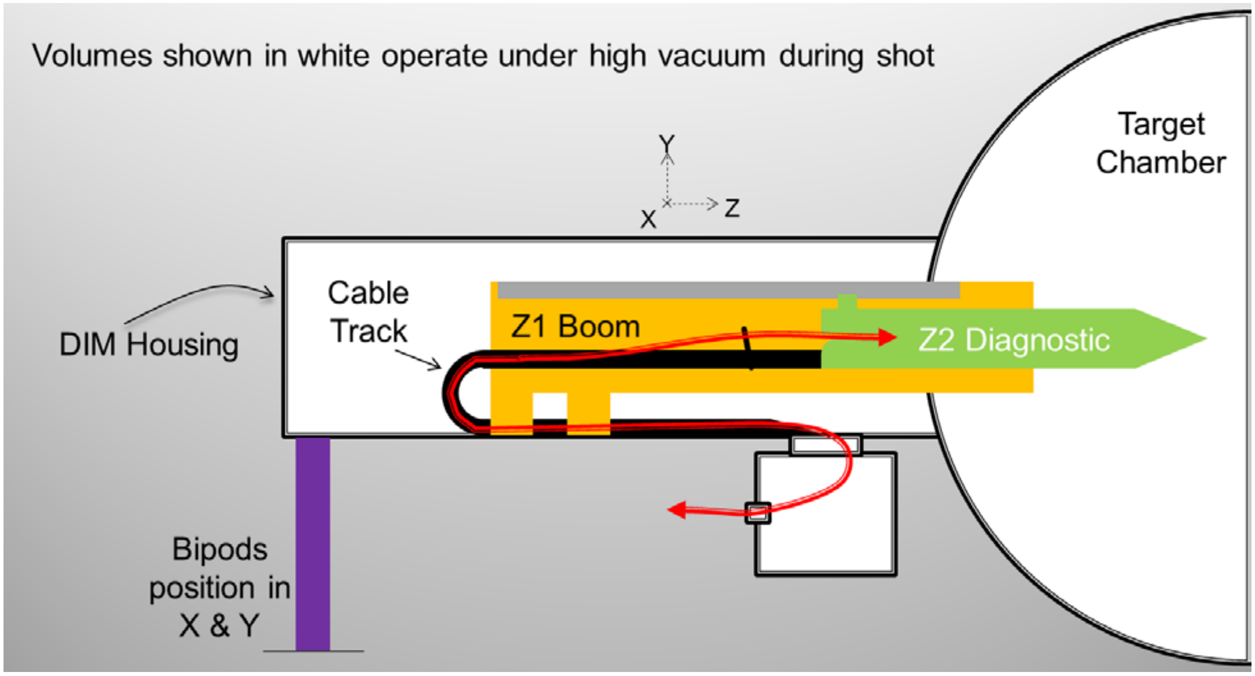

Figure 3 – Simplified Schematic of an Equatorial Diagnostic Instrument Manipulator (DIM)

The focus of this requirements document is on the transport and handling (T&H) equipment for the DIM-based diagnostics, known as the Diagnostic Load Packages (DLPs). Due to the potential radiological hazards present in the unique NIF operating environment, these interchangeable DLPs must be transported through the uncontaminated NIF facility to local areas for contaminated operations (CZs), which are either the areas immediately surrounding and including the DIMs themselves or the dedicated offline labs in which contaminated DLPs can be refurbished, upgraded, and tested. This mode of operating in a contaminated environment requires the implementation of specific transport and handling equipment to contain contaminants, protect the DLP, and keep worker exposure to as low a level as possible.

The current DLP T&H system is composed of a series of unreliable, sub-optimal cart and container subsystems that require complicated interactions and unreasonable physical exertion to operate. A pictorial and written description of each subsystem (Orange Carts, Running Gear, DHU, Blue Carts, and DSUs) is provided in Section 3 underneath the discussion of the "as-is" contextual description. The current system requires multiple operators, is ergonomically suboptimal, is unreliable, and adds much time to the operations schedule due to unnecessary subsystem exchanges. Even if the subsystems were optimized within their own subsystem boundaries, the overall T&H system is sufficiently inefficient and inadequate to the extent of requiring a complete redesign from the conceptual level down. The rationale, concepts, and requirements development process for this redesign effort are discussed within this document.

a. Mission

Design a transport and handling system for DIM-based diagnostics that will increase worker safety, improve ergonomics, provide reliable operation, and reduce diagnostic turnaround time while maintaining the NIF core values of safety, quality and reliability.

b. Goals (What We Wish to Accomplish)

The current transport and handling system for a DIM-based DLP is increasingly unreliable, requires multiple operators, and is cumbersome to use. The redesigned system should:

- Maintain or improve the existing interfaces to the existing infrastructure (DIMs, alignment stands, DLPs)
- Reduce diagnostic turnaround time
- Protect the diagnostic from excessive handling
- Increase worker safety
- Increase system safety
- Improve reliability of transportation and handling
- Improve reliability of diagnostic installation and removal
- Reduce the required number of operators

c. Objectives (Description of What Will Be Done)

- Decrease diagnostic transaction time by 50%
- System must be robust and safe for diagnostic
- Greatly reduce any “lost time” accidents resulting from this operation
- Satisfactory reliability of the transport and handling system (Target MTBF ~ 10 years)
- Maximum of two individuals to operate the system

d. Business Rationale

- Reliability of current Orange Cart/Blue Cart systems is subpar
    - Chain derailment
    - Chain binding
    - Metallic galling
    - Lubrication/rotary joints improperly designed
    - Precision/interchangeability of assemblies
    - Operations time lost to repair
    - Engineering time lost to repair and redesign
    - Efficiency time lost due to standard operations
- Operator stress is high
    - Minor safety incidents have occurred
    - Ergonomics are not satisfactory
    - High input force is required for Orange Carts
    - Man-handling of carts is required for alignment of DHU
    - DHU adjustment (both coarse and fine) requires excessive time

- Overall system concept flawed
    - Subsystems were designed before total operational impact and concept were understood and developed
    - Numerous subsystem interfaces and exchanges (i.e. rigging, DHU-to-DSU exchanges, Running Gear-to-Orange Cart DHU transfers, Polar DIM DLP transactions) increase operational overhead significantly beyond an optimal level

e. Stakeholders

Because there are many stakeholders with a vested interest in the success of the DLP transport and handling system, almost all of the human stakeholders were interviewed. In doing so, they were asked a few pointed questions:

- "What do you, and don't you, like about the existing system?", and
- "If you could start with a blank sheet of paper, what would the new system look like?"

While many comments and suggestions were presented, not all were accepted for the final concept. In reading through this in-depth list, there are very clear themes throughout each interview.

The list below is a condensed version of what was recorded from those interviews.

i. Passive Stakeholders

The passive stakeholders are identified as individuals, entities, other systems, standards, protocols, procedures, or regulations that influence the success of the system or solution but do not directly use or operate the commissioned system.

1. Target Diagnostics Engineering (TDE) – TDE is the organization responsible for the design, integration, operation and maintenance of all diagnostics in the NIF facility, including the T&H system and diagnostics that use the system for transport. This group includes several stakeholders listed below:
    a. DIM RSE/Positioner CCB5 & DIM IPT – Bill Edwards
        i. Difficult to use, unreliable, inefficient
        ii. Current alignment to DIM is sub-par, laser guided not necessary
        iii. Should be motorized, not manual (no hand crank)
        iv. One system for DHU/Running Gear, to go under TASPOS/DIMs, and work with EDIM and PDIM
        v. Look at entire system and design one that works for 391/581/DIM/OSB/Storage/Alignment
        vi. Smaller footprint, ergonomics, tool-less, maneuverability
        vii. Look at redesigning DHU, currently over-designed, too heavy, too bulky, vacuum ability not utilized
        viii. Support rad ops, consider low activation material
    b. Diagnostic RSE's – Ben Hatch and Brian Felker

i. Minimize excessive vibration during transport to protect damaging the diagnostic, need requirement as to what g force diagnostic can safely manage. Possible adjustable wheels or springs for dampening
ii. Height adjustability, need to secure in place so it doesn't drift or bump into something else, ability to fit under TASPOS/TARPOS
iii. Interface with alignment stand, DIM, DHU, Blue Cart, storage garage
iv. Combine Running Gear and Orange Cart
v. Excessive transactions from cart, to stand, to garage, or DIM; consider integrating a solution to eliminate the need to transfer.
vi. Consider reducing the need for rigging or specialized training
vii. Seismic considerations
viii. Motorized or automatic, not manual or hand crank

c. Diagnostic RS's –Bob Kauffman's Diagnostic Change Control Board, Level 5 (CCB5)
d. DIM Dance IPT – Ben Hatch (see 1.b)

2. Rigging – all rigging in the facility must be thoroughly reviewed, documented and approved by the authorizing individual; for the NIF facility, it is Hanson Loey.
    a. Decouple the T&H system from the physical details of the DIM hardware (rails)
    b. Optimize process for adjusting the rigging hardware to accommodate loaded vs loaded DHU CG, currently it is cumbersome
    c. DHU over-designed
    d. Labeling what is inside DHU – consider barcodes scanners for inventory control
    e. Rotunda crane is restrictive, riskier than desired
    f. Engineering design of DHU does not have an efficient load path w.r.t. rigging
    g. Joystick control, one person operation, 6 degrees of freedom adjustability, combine Running Gear and Orange Cart, DIM railing,
    h. Lock down future rad ventilation requirements (Hi-Z, tritium, Be)
    i. Ribbon cable idea, plug in power on the outside
    j. Look into the LAT, OAB type transporter (Tim Sarginson)
    k. Uniqueness of rigging hardware is a good thing to prevent parts from migrating or falling out of calibration
    l. Rigging has to be inspected every month
3. NOM – the NIF Operations Manager is responsible for overseeing all of NIF operations. The NOM is a stakeholder in the sense she/he is concerned with safe, reliable and efficient operation in the facility but will not actively interface with the T&H system.
4. NIF operations & scheduling – this includes input from Target Diagnostic facility scheduling and coordination, Jim Cox, and the TAO Work Center Supervisor, Mark Wilson. Both stakeholders must account for the time it takes to operate this system when coordinating multiple activities and planning manpower.
    a. Like how DHUs can be transported on Running Gear, eliminates the need to open the totem door
    b. Time and difficulty to adjust Orange Cart

c. Orange Cart includes too many functions, instead break system down into multiple functions and consider multiple subsystems to satisfy each functional need
d. Need a way to align DHU with DIM and install diagnostic, must work in vertical and horizontal positions. Current method with a tape measure is inefficient and ineffective.
e. Redesign DHU - DHUs are built for vacuum, if not a true requirement consider a different DHU system to decrease the weight requirement, would improve ease of handling for operators
f. More DHUs and storage locations
g. Manual operation of Orange Cart is not desirable
h. Transportation on hard wheels is difficult and causes excessive vibration

5. Facility Operations and Maintenance (FOM) – this group could indirectly interface with the T&H system because they maintain the facility, building systems, vacuum systems and must approve any new facility installation.
6. Aesthetics – the NIF Aesthetics Committee ensures that any new system brought into the NIF facility conforms to the existing guidelines.
7. Cleanliness – the NIF Cleanliness Committee ensures that any new system brought into the NIF Target Bay adheres to the existing cleanliness protocols.
8. Materials – the NIF Materials Committee ensures that any new system brought into the NIF Target Bay adheres to the existing cleanliness protocols.
9. Engineering Quality – Scott Winters
    a. Customers not currently satisfied with operational quality
    b. Current design is inefficient, not easy to use, not operable ergonomic
    c. Current design met a short-term need, now need a long-term solution
    d. Consider COTS – proven technology, maintainability, operability, reduce risk and expense
    e. Consider scalability of solution, increase in use, NIF operations, transactions
    f. Explore all available technologies to find the best solution
    g. Revisit what the system should accomplish and look at expanding the current system boundary
10. Target Bay CCB5 – Perry Bell and Rich Zacharias
    a. Mitigate significant g force seen on diagnostic during transportation
    b. Minimize footprint of system (Orange Carts are very large)
    c. Automatic or electric adjustment instead of manual (no hand crank)
    d. Reconsider DHU system , is the overdesign necessary, consider open top system, rad controls for an open top system
    e. Limited number of tools
    f. ROI for a 30 year program

ii. Active Stakeholders

The active stakeholders are individuals, entities, or other systems which will actively interact with the system once it is operational and in use.

1. Target Diagnostics Engineering
    a. DIM T&H RSE – Robert Plummer
        i. Subpar vendor quality of the parts
        ii. Parts and system are imprecise, makes adjustment difficult
        iii. Rotating joints not designed well, no bearings or bushings
        iv. Lack of precision makes it tough to diagnose on individual carts so PL's don't differentiate between which cart,
        v. Current system is so custom it is difficult to diagnose issues
        vi. Not designed for maintainability, current system maintenance is an art, no maintenance document,
        vii. Lack of precision alignment capabilities for techs, too limited in degrees of freedom, low ease of alignment for cart.
        viii. Since this RSE is part of the interview team, the remainder of his comments has been discussed by other stakeholders.
        ix. Would be nice to lock container/DHU for PTS considerations in future
2. Rigging – approved by Engineering Quality but training is performed by Bill Edwards.
    a. Quick release or tool-less hardware to secure the vessel or T&H equipment for eventual rigging into PDIM
    b. Roll up to PDIM/pick it up/ clamp something on/tilt up and go
    c. Does DHU vessel need to be rigged at all?
    d. Does DHU need to be separate from T&H system??
    e. System should be lightweight
    f. Reduce required number of operators
3. TAO – the Target Area Operators are the technicians (or the end users) who maneuver and utilize the system multiple times a week. This group has the most hands, eyes and ears on the system and input for requirements from this group is paramount.
    a. Too high for current crane operation behind EDIMs
    b. Automation for most aspects of movement/positioning/raise/lower
    c. Must be able to go under TARPOS/TASPOS
    d. Integrate Orange Cart and Running Gear
    e. Smaller footprint
    f. Maneuverable around entire TB2 level, PDIM ramp
    g. Wheel positioning, not under CG, ease of movement
    h. Handle height and steering of DHU on Running Gear is acceptable
    i. Shock absorption of transport unit
    j. One person operation
4. Target Diagnostic Factory – these technician teams are responsible for performing maintenance on the systems per the RSE's instructions. They also use the system in the offline refurbishment labs (alignment stations) where they perform upgrades, testing, and repairs to the DLPs (Rekow/Hamblen/Bopp)
    a. Electric or automatic mechanism, not manually powered (crank)
    b. Height adjustability to access floor, DIM, alignment stand, and garage

c. Reliable – eliminate chains falling off and decrease required maintenance
d. Ergonomics
e. Parts should not be removable (handle), and no small parts since they can be lost or damaged
f. Multiple transfers to cart/stand/garage/dim for single diagnostic is inefficient
g. DHU tube helps from a rad standpoint
h. Consider taking requirements to a company (like Alumalift) to build a custom system
i. Storage rack needs DPV to help decontaminate the DHU internals and decrease turnaround time
j. Vern has a concept idea that was proposed for the original T&H system

5. Target Diagnostic Factory Manager – Tim Sarginson
    a. Quick-release features for the DHU end spools would be nice
    b. Eliminate DSUs all together
    c. DHU movement is the most problematic and biggest area for improvement
    d. DHUs should be smaller and possibly square shaped; lots of unused internal space
    e. Integrate a purge/vent system (with alarm?) into new system
6. RCT – Richard Beale is the RSO; he must approve all radiation controls at NIF, especially for the new transport and handling system
    a. Excessive footprint and size of system
    b. Current radiation controls are overkill for NIF's level of contamination, but must consider scalability for increase in contamination or types of materials used in shots
    c. Simplicity is best for rad controls
    d. Consider QD for purging – inlet HEPA filter with QD to prevent dirt, eliminate 4" DPV hose
    e. Method of purging through passive outgassing or active vent/pump
    f. Reduce cart transaction time for ALARA
    g. Engineering the new solution for self-aligning to the DIM with less operator interaction is key
    h. Ability to support high Z shots, which means fully enclosing the DLP if needed
    i. Choose low activation materials for the design
7. Vacuum – the vacuum system at NIF is an important interface for contamination mitigation. The vacuum system manager, Allen Riddle, is a stakeholder and his only expectation is to be informed of future design concepts that would dramatically affect DPV. He is willing to support our design effort as required.
8. The following three active stakeholders are not currently involved in the system. However, depending on the concept selection for the new system, their involvement may be required:
    a. Hardware Controls Systems (active) – Taranowski
    b. ICS (active) – Reed
    c. ICCS (active) – Brunton

f. Stakeholder Summary

With considerable input from many different stakeholders, it was obvious which concerns were repeated and what expectations they had for the new system. Their problems with the existing system are stated below, followed by the sacred expectations for the new system.

1. Shock loads can damage the DLP; it must also be physically protected from mechanical damage
2. System has a large footprint size, system too heavy
3. Manual height and alignment adjustment difficult, especially to DIM rails
4. Two carts bolted to together for Orange Carts makes things more difficult and should be combined for new system
5. Combine Running Gear and Orange Cart functionality into unified system for the new concept to eliminate subsystem exchanges
6. Maneuverability of the current system is cumbersome (number and type and location of wheels for all systems)
7. The containment system (DHU functionality) needs optimization
    a. Spool handling and weight
    b. Tool quantity
    c. Overly robust design
    d. Rigging straps are awkward and get in the way; restrict fine-adjustment
    e. DPV trunk heavy and awkward to connect
    f. Incorrect or dual saddle positions cause confusion and inefficiency
8. Design quality and reliability of Running Gear and Orange Carts is poor
    a. These are currently separate subsystems that should be combined for the new system
    b. Chain breaks and falls off
    c. Parts gall, friction too high
    d. Hand breaks on Running Gear are often broken
    e. Tires go flat (must be more reliable than automotive tires)
9. One person operation is critical for the new system
10. Automation/motorization or self-propulsion is critical for the new system
11. DSU conversion or elimination is needed

g. Sacred Expectations/Key Stakeholder Acceptance Criteria

Based on the extensive interviews with stakeholders and domain knowledge of the system, the design team distilled the stakeholder summary above into an inclusive list of the 7 sacred expectations below:

1. Simple operation & easy to use
2. Safe for operators (ergonomics)
3. Doesn't damage DLP
4. Works with existing infrastructure (DIMs, DHUs, DAS, building, etc.)
5. Reliable operation and minimal maintenance
6. Provides radiation controls
7. Dramatically reduced time to transact or exchange DLP

h. Context Diagram

Reference Section 2 for the Context Diagram

3. System Operational Context and Reference Operational Architecture

To better understand the proposed system concept and its architecture, it is helpful to discuss the reference architecture of the legacy implementation of the current system.

a. "As-Is" Contextual Description of Current DLP T&H System

The DIM-based DLP transport and handling system is a series of disjointed, suboptimal subsystems that accept any DLP for transport between various sites within the NIF facility and interfaces with various install locations with an adjustable mechanism, all while mitigating contamination and physically protecting the DLP (Figure 10). The constituent subsystems that comprise the overall T&H system are:

1. Diagnostic Handling Unit (DHU) – a sealable container designed to contain tritium, protect the DLP, and dock to installation destinations for the DLP (Figure 4).

Figure 4 – Diagnostic Handling Unit (DHU)

2. Orange Cart – an unreliable and cumbersome transport cart capable of transporting a DHU through the facility, raising and lowering the load, and providing limited fine adjustment to facilitate DHU docking to its destination (Figure 5).

Figure 5 – Orange Cart

3. Running Gear – a "low-boy"-style transporter cart that allows for greater maneuverability throughout the NIF facility due to its small footprint; raising and lowering of the DHU is not possible with this system and therefore requires rigging operations to manipulate the DHU (Figure 6).

Figure 6 – Running Gear

4. Blue Cart – previous iteration of the Orange Cart system that does not support contaminated operations because it interfaces directly with the DLP and cannot support the DHU hardware; its use is limited to transport from B391 to B581 (NIF), Figure 7.

Figure 7 – Blue Cart

5. Diagnostic Storage Unit (DSU) – a sealable container design to only store a DLP; it is generally inefficient and not preferred by the operations staff, Figure 8.

Figure 8 – Diagnostic Storage Unit (DSU)

To start the process, the Target Diagnostic Factory will load the system with a DLP from the build facility in B391, the factory alignment stand in B581 (i.e. NIF), or the storage garage in B581. If the system starts in B391, the TDF will move the DLP through B391 on a Blue Cart and load it into a truck to transport to NIF. If the system starts at NIF, the TDF will hand off the loaded DHU on an Orange Cart to the TAOs, who then rig the system onto the Running Gear and move the system through the facility, including multiple floors, elevators, doors, and under equipment. The next location could be a DIM, alignment stand, or storage garage. Once the system reaches its location, the TAOs will rig the loaded DHU back onto an Orange Cart and coarse adjust the height of the Orange Cart before finely adjusting the system to mate with the location (Figure 9). Diagnostic Positioner Ventilation (DPV) is connected to the system to purge contamination while TAOs are working with the system.

Figure 9 – Loaded DHU on top of an Orange Cart Docked to an Equatorial DIM

If the DLP-installation location is the Polar DIM, the system must first be rigged and rotated vertically in order to load the DLP into the DIM. Once the DLP is installed at its destination, an RCT will swipe the exterior of the system to release it from the CZ. The system will then be transported back to one of the starting locations to start the process over again. Alternatively, the process can be executed backwards, where the system starts at the DIM to accept the unloading of a DLP and then ends at a final location of either the TDF alignment stand or storage garage.

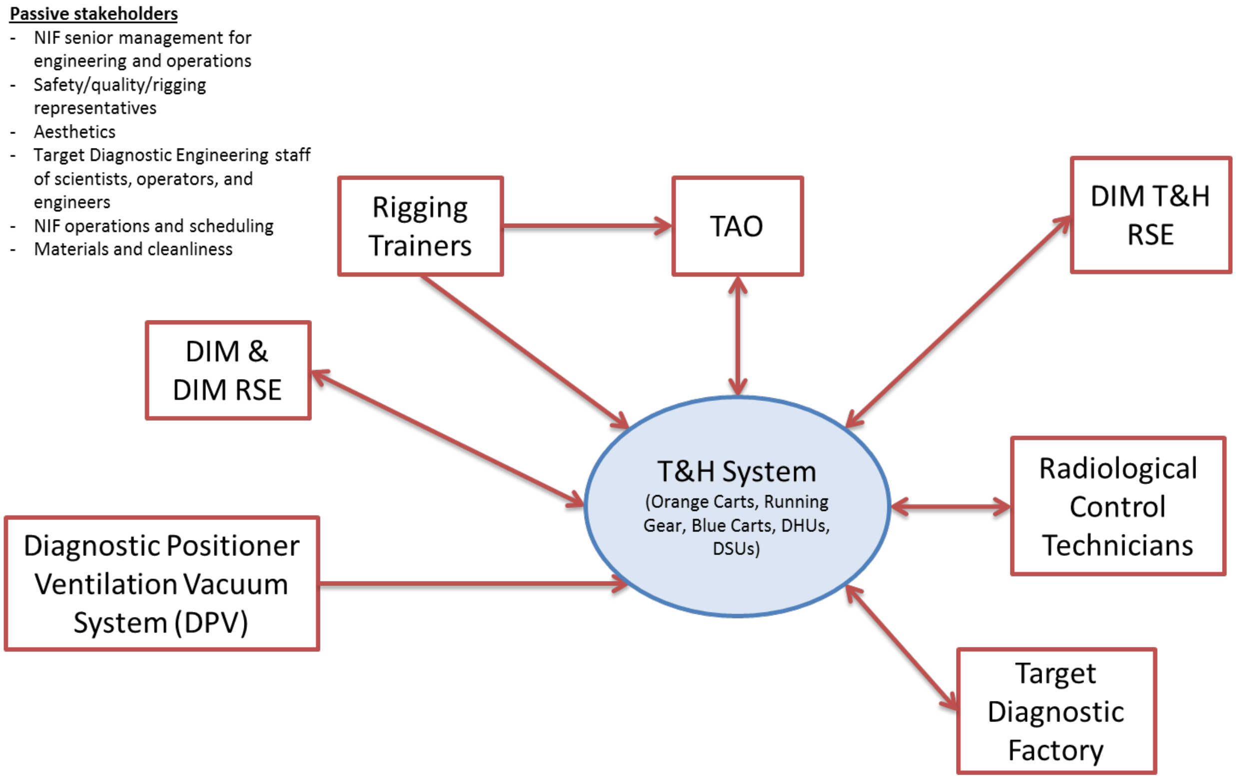

Figure 10 – "As-Is" Context Diagram for Existing DLP T&H System

b. "To-Be" Contextual Description of New DLP T&H System

As a result of the interview process for gathering stakeholder expectations and requirements, a common vision for the new system emerged, which is summarized in Section 1 under the Stakeholder Summary heading. The new DLP T&H system will be comprised of a single transporter that performs the four vital functions of DLP operations: transport, containment, raising/lower, and fine adjustment (Figure 11). Rather than having a separable container that must interface with two different transporters and extensive rigging operations, this integrated concept has the significant advantage over the current system of consolidating the three major current subsystems (Orange Cart, DHU, and Running Gear) into a single transporter. With thoughtful design development, the design may ultimately eliminate the need for storage-specific containers (like DSUs) and uncontaminated DLP transport carts (Blue Carts).

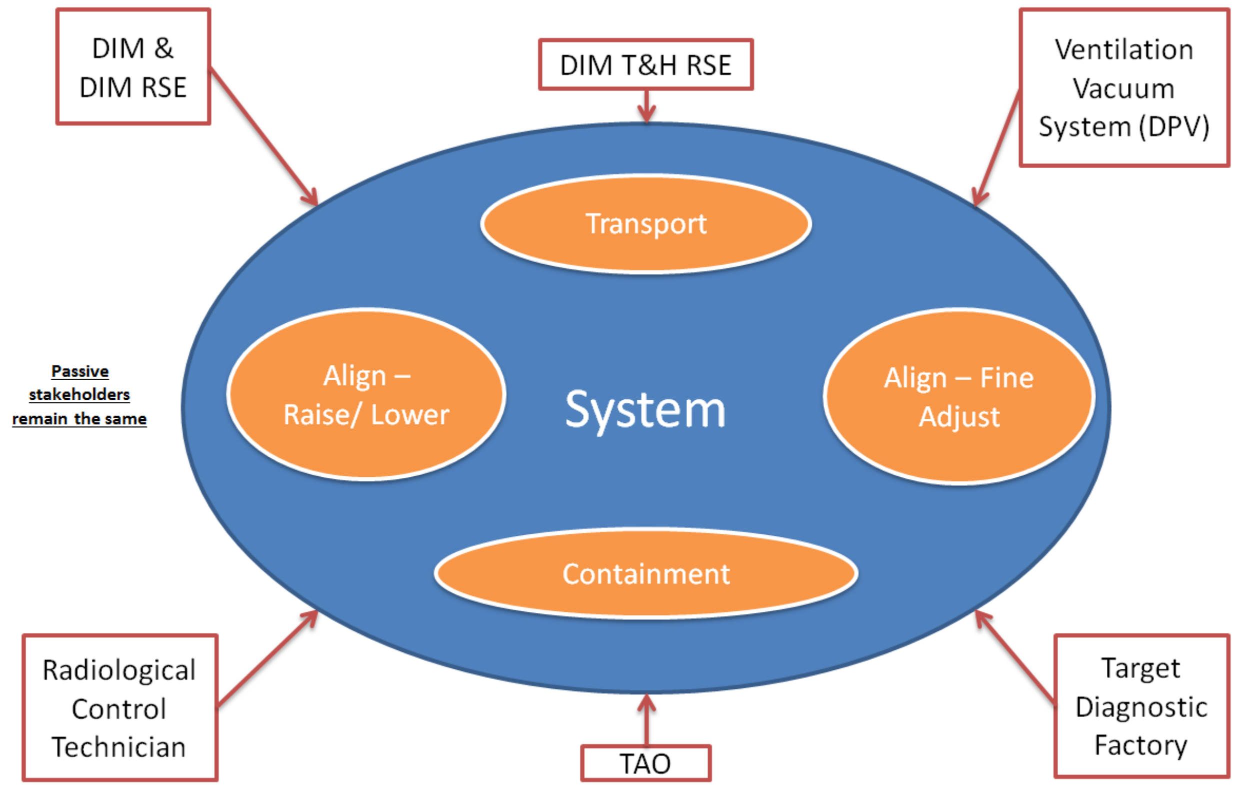

Figure 11 – "To-Be" Context Diagram for New DLP T&H System

The system interfaces and boundaries remain largely the same, but the chosen concept hardware will be vastly different. This is covered in detail later in this document (Sections 5 and 6). The only significant difference with the new system boundary is the elimination of the interface to the rigging training staff since the system will not require rigging, though certain system interfaces may have the ability to be rigged. Figure 12 identifies the steps eliminated from the overall DLP transaction process by implementing the new DLP transporter system. Eliminated tasks are highlighted in yellow.

As-Is vs. To-Be Contextual Comparison			
	Steps	**As-Is**	**To-Be**
1	DLP built	X	X
2	Load from alignment stand in 391 to blue cart	X	X
3	Transport blue cart through 391 to Bay 3 rollup door	X	X
4	Load blue cart into box truck	X	X
5	Drive box truck to OSB elevator airlock at SY2	X	X
6	Unload blue cart into airlock	X	X
7	Transport blue cart to:	X	X
a	OSB 2006	X	X
b	GDE	X	X
8	Load DLP on alignment stand in:	X	X
a	OSB 2006	X	X
b	GDE	X	X
9	Start free release of blue cart	X	
10	Perform alignment/characterization of DLP on alignment stand:	X	X
a	OSB 2006	X	X
b	GDE (does not have rack or cabling, cannot perform functional test)	X	X
11	Load DHU on orange cart	X	
a	OSB 2006	X	
b	SY2	X	
c	GDE	X	
d	Behind EDIM	X	
12	Transport DHU to alignment stand	X	X
a	OSB 2006	X	X
b	GDE	X	X
13	Load DLP into DHU	X	X
14	Conditionally release or CZ/CZ swap of cart/DHU package	X	X
15	Rig DHU onto running gear	X	
a	OSB 2006	X	
b	GDE	X	
16	Transport DHU on running gear to:	X	X
a	SY2 storage	X	X
b	DIM (Equatorial or PDIM)	X	X
17	Rig DHU onto:	X	
a	SY2 storage (complete)	X	
b	Orange Cart for EDIM	X	
i	Lower orange cart a few inches with crank, DHU crane is not high enough to lift DHU above orange cart saddles	X	
ii	Raise orange cart with crank to approximate EDIM height	X	
c	PDIM	X	
18	Prep DIM for loading	X	X
19	Prep DHU	X	X
a	EDIM: remove end caps, DPV, latch to hitch pin, tritium sample	X	X
b	PDIM: bolt on front stand spool, tritium sample, unbolt unnecessary DHU hardware that interferes with 60' platform	X	
20	Position DHU	X	X
a	EDIM: position DHU behind DIM, fine adjust height/roll/yaw/pitch	X	X
b	PDIM: rig DHU to rotate DHU vertical and lock floor hatches in place	X	
21	Load DLP to DIM	X	X
a	EDIM: hook up blue box, drive to end of DHU rack, push by hand, continue to drive onto DIM rack to CTC load position	X	X
b	PDIM: hook up blue box, drive to end of rack, disconnect blue box, then rig to DIM, drop into DIM, engage rack, reconnect blue box, continue driving	X	X
22	Continue with DLP installation	X	X
23	Close up DHU	X	X
24	Start free release of:	X	X
a	DHU	X	
b	Orange Cart	X	X
c	Running Gear	X	

Figure 12 – "As-Is" vs. "To-Be" Context Description (Yellow Indicates Eliminated Steps)

4. System Drivers and Constraints

Since the first inception of the current transport and handling system, it was acknowledged that the system was designed to meet a short-term need and was accepted by both engineering and operations stakeholders at the time as NOT a long-term fix. The short-term nature of the solution has been exhausted, and recent minor incidents have revealed flaws with the existing design that could be improved to further optimize safety.

The drivers of the design, as alluded to above, are to increase worker safety, improve ergonomics, provide reliable operation, and reduce diagnostic turnaround time while maintaining the NIF core values of safety, quality and reliability. These drivers manifest themselves in the form of tangible performance requirements that will include maneuverability, the time required to perform a major vital system function (i.e. raise/lower DLP), the quantity of rigging operations, the number of subsystem interfaces and exchanges, and fine adjustability capabilities, etc. A detailed list of requirements is provided in Section 7.

There are also many constraints to consider which either actively or passively impact the design:

1. NIF Building – the NIF building is a stakeholder that provides constraints on the system due to the limitations of door sizes and placement, elevator size and placement, and additional constraints due to existing diagnostics and Positioners, facility conduits and cabling, and the routing of utilities.
2. DIM – the Diagnostic Instrument Manipulator (DIM) actively interacts with the system but is not an actual person. The system must be able to interface with the as-built DIM.
3. DLP – the Diagnostic Load Package (DLP) actively interacts with the system because it must be loaded and unloaded into its destination, protected during transport, and kept fully contained within uncontaminated and buffer zones. Each DLP is also unique and comes potentially with its own requirements.
4. NIF DHU storage rack & garage – the NIF DHU storage rack and garage at SY2 provides a constraint on the system solution since the storage racks are built and in place and there is an expectation to utilize the existing storage system.
5. B391 storage garage – the storage garage in B391 provides a constraint on the system solution since the storage racks are built and in place, and there is an expectation to utilize the existing storage system.
6. Weather – acknowledge external forces, like weather, could affect the solution when transporting between buildings or when engineering for seismic concerns
7. Temperature – must adhere to facility standards for system temperature dissipation
8. Existing standards – any and all new designs fielded at NIF must undergo the rigor of review to ensure they adhere to the design safety standards of LLNL. This applies to pressure safety, seismic design, and rigging safety. Additionally, NIF carries its own more stringent requirements for material selection due to cleanliness and radiation effects.

5. Operational Scenarios

The operational scenarios of the existing system can be greatly simplified with the implementation of a new transporter system. These current operational scenarios were further clarified during the stakeholder interviews in the form of constraints or functional requirements. The system must interface with existing facility structures, thus the functional requirements and operational scenarios are constrained by these interfaces. The scenarios listed below identify the various interfaces and functional locations and abilities required for the new system. The most informative scenarios will be represented in a graphical context using sequence diagrams.

Due to time and resources constraints in compiling this document, the “to-be” operational scenarios will be validated with the end user technician stakeholders as part of the review process preceding the Conceptual Design Review at NIF.

The system will:

- Transport the DLP
    - From B391 to B581
    - From alignment stand to garage or TB or SY, including:
        - Transport from GDE to 90-315
        - Transport from GDE to PDIM
        - Transport from GDE to 90-78
        - Transport from OSB to 90-315
        - Transport from OSB to 90-78
        - Transport from OSB to PDIM
        - Transport from OSB/GDE to SY storage
- Install/Remove DLP to/from DIM
    - Raise and lower DLP
    - Align DLP to DIM
- Protect the DLP
- Contain contamination

a. "As-Is" Operational Scenarios for the Current System

i. Transport the DLP to the PDIM

Transporting the system from the TDF (OSB/GDE) to the PDIM is a more complex operational scenario than the others (Figure 13). All of the steps required to transport the system to the PDIM are the same as 90-78 or 90-315, except the system must roll under TAxPOS on Level 2 or change orientation of the system for rigging at Level 5.

The scenario starts with the TDF technician who prepares the DLP for NIF. The TDF loads the DLP into the DHU on an Orange Cart, and then notifies the RCT to swipe and release the system so it can be transported through the facility. The TDF then rigs the DHU off of the Orange Cart onto the Running Gear. The TDF transfers ownership to the TAOs, who then move the DHU on Running Gear to the SY2 elevator, loading it into the elevator. The TAO with DHU on Running Gear exit the SY2 elevator on Level 5 of the TB and roll the DHU through the double doors. The DHU on Running Gear is then rolled up the ramp and a wedge is installed so it does not move.

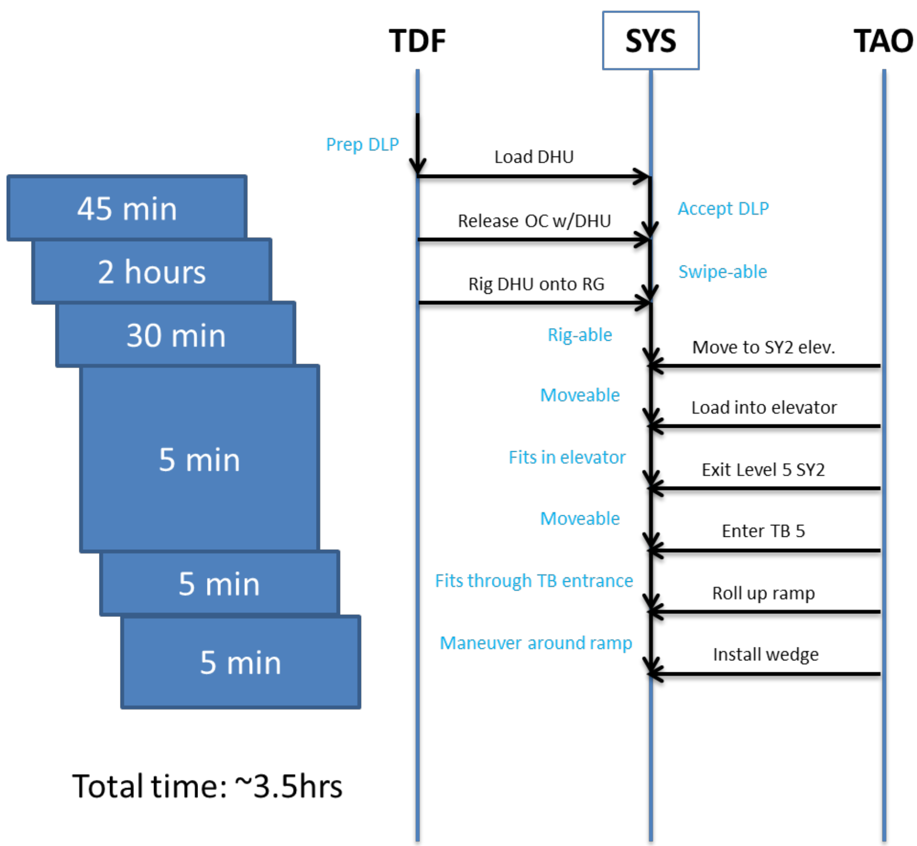

Figure 13 – Transport DLP from TDF (GDE/OSB) to PDIM

ii. Install the DLP into the PDIM

Installation of the DLP into the PDIM (Figure 14) is a more complex operational scenario than the others, but both the PDIM and EDIM operational scenarios will be described in the next two sections.

Once the system is on the ramp and the wedge installed, the TAO attaches a stand-up spool to the DHU. Extra parts on the DHU are removed, tritium is sampled, and then rigging hardware is attached to the DHU. The DHU is then rigged through the hatch at 60' and then aligned to holes in the floor at 50'. The top portion of the DHU is locked to the 60' platform while the bottom portion is bolted to the 50' platform. The rigging attached to the DHU is removed along with the rear end cap, allowing access to the DLP inside the DHU. Rigging equipment is then installed to the DLP to lift it from the DHU over to the DIM, and lowered into the DIM. The rear end cap is reinstalled on the DHU, the rigging equipment is reinstalled on the DHU, and the DHU is undocked from the 50' and returned to the horizontal position.

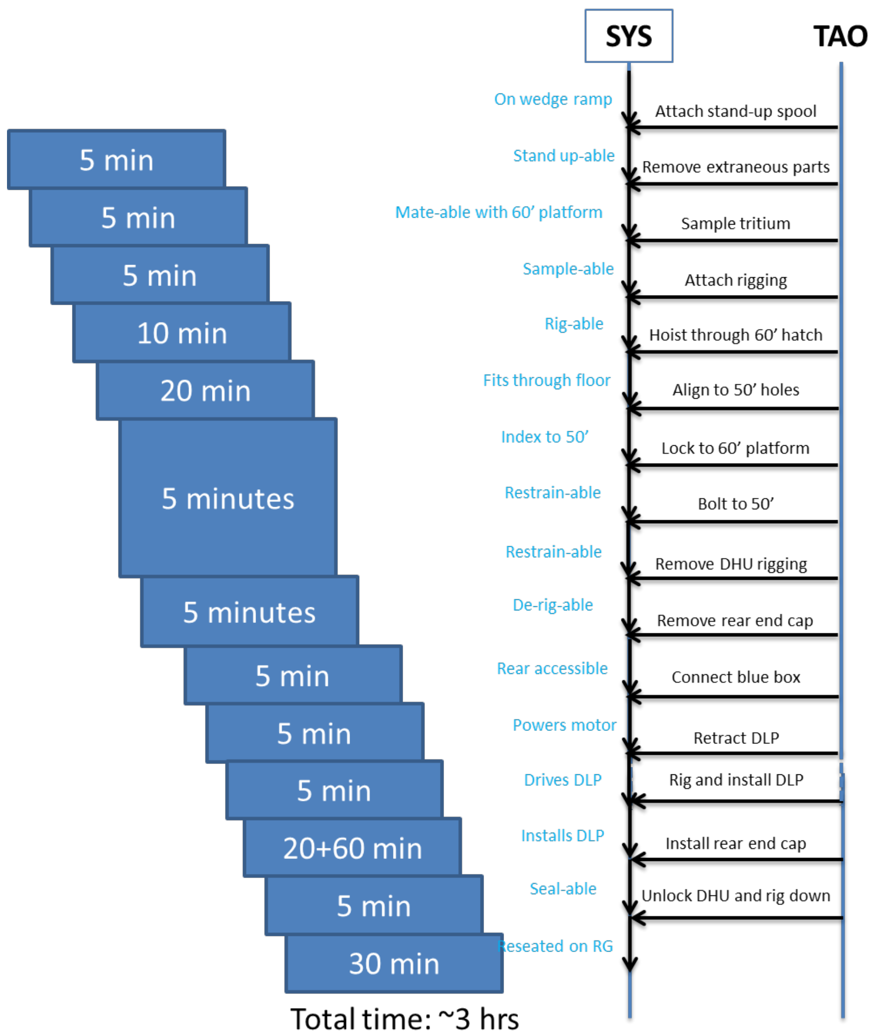

Figure 14 – Install DLP to PDIM

iii. Install the DLP into the EDIM

Once the system is located near the back of the EDIM, the TAOs will lower the Orange Cart so it is low enough for the DHU to pass over the Orange Cart saddles while hoisted on the crane. The DHU is rigged onto the Orange Cart, and the cart is raised back to the DIM-docking position. Tritium is sampled and then end caps are removed. The DPV trunk is attached to a port on the DHU and turned on to allow negative airflow over the diagnostic, thereby drawing any contamination away from the operators. The hitch post is attached, allowing the Orange Cart to be rotated into position behind the DIM. Fine adjustment is performed manually by 1) unstrapping the DHU and rolling it within the saddles, 2) pushing it closer to the DIM, and 3) raising or lowering each Orange Cart separately for pitch; this process is iterative and can take multiple attempts. Once the DLP in the DHU is aligned to the DIM, the blue box is connected externally to the DHU to then drive the DLP into the DIM. The blue box is then disconnected, the Orange Cart rotated away from the DIM, DPV disconnected, the hitch pin removed, and end caps reinstalled (Figure 15).

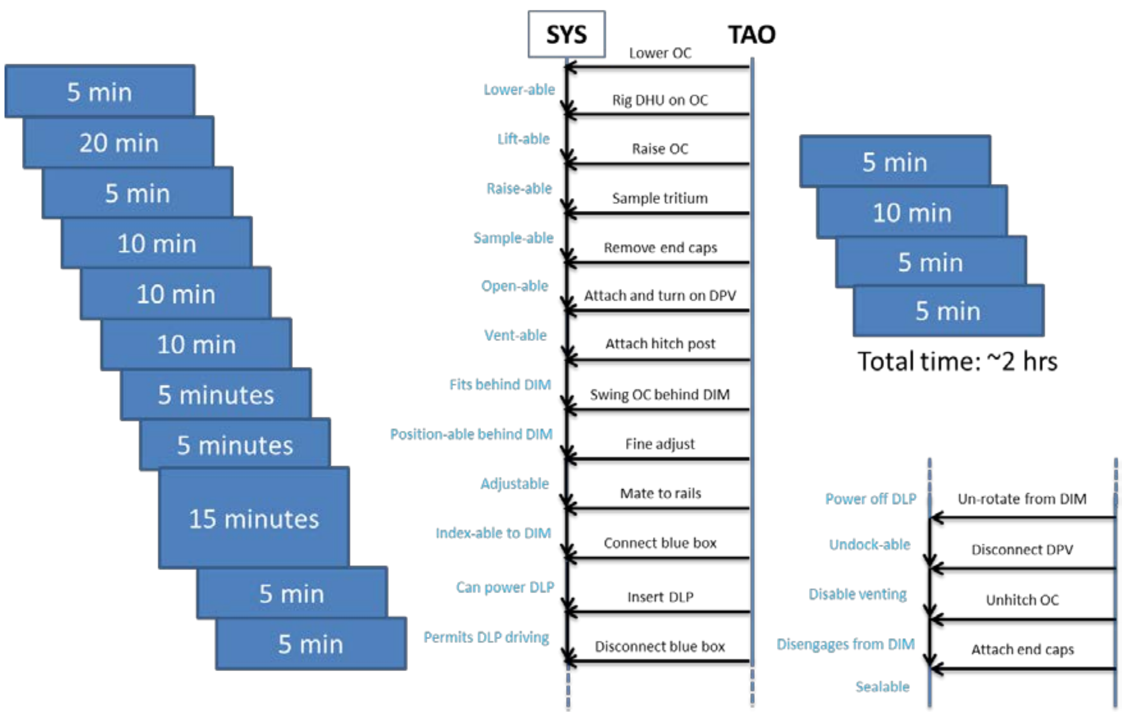

Figure 15 – Install DLP to EDIM

iv. Protect the DLP

The system must protect the DLP for the entire duration the DLP is housed in the DHU. The DHU protects the diagnostic from facility elements, including temperature fluctuations and moisture. During transport, the system is critical in isolating excessive vibration from the diagnostic, but the current system has no mechanism by which to isolate shock loads from crossing thresholds and differing surfaces. Some diagnostics have sensitive components that may become damaged if the system does not isolate the vibration forces. The inability to damp excessive vibration is a design oversight to be rectified in the new design.

The system has an interface for a vent/purge system to assist in mitigating contamination. During use, DPV is connected to the DHU to allow ventilation of the system to remove contamination while the workers are using the system. This is also the case when the TDF is utilizing the system in the OSB or GDE.

v. Contain Contamination

The system must be able to contain the existing contamination seen at the NIF facility while protecting the workers from contamination during handling. The existing system of the DHU is deemed excessive by the RSO and is overkill for the amount of contamination currently seen in the facility. The new system does not need to be as robust but should consider scalability if new types of contamination are introduced into NIF.

b. "To-Be" Operational Scenarios

i. Transport the DLP to the PDIM – New Context

As mentioned in Section 2, the "to-be" context will be comprised of a single transporter that contains integrated operations for the four vital functions. By combining the Orange Cart, Running Gear and DHU, the rigging operations that used to take up much of the time have been eliminated, directly yielding a cost savings of at least 30 minutes per rigging exchange.

The TDF loads the DLP into the transporter, and then notifies the RCT to swipe and release the system so it can be transported through the facility. The TDF transfers ownership to the TAOs, who then move the transporter to the SY2 elevator, loading it into the elevator. The TAO with transporter exit the SY2 elevator on Level 5 of the TB and roll the DHU through the double doors. The transporter is then rolled up the ramp and into position (Figure 16).

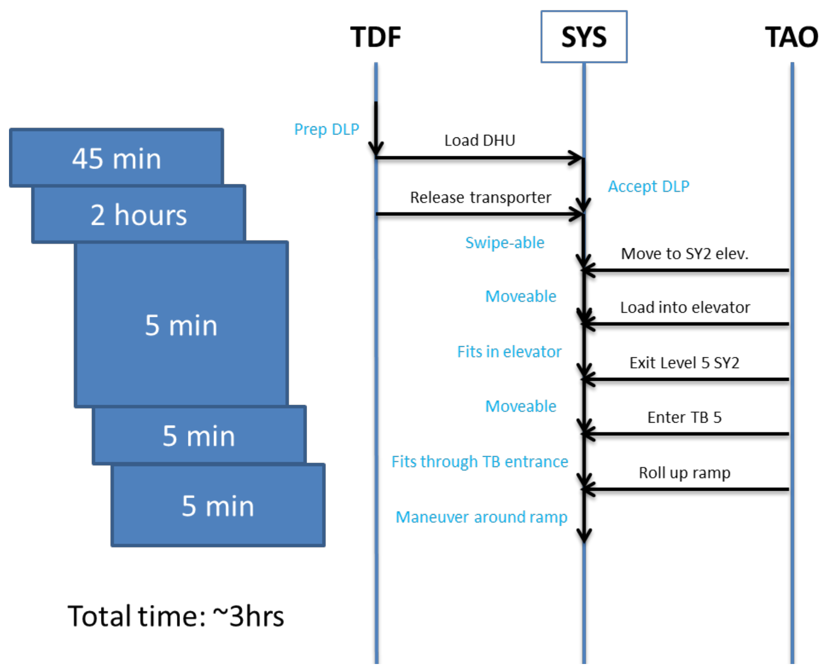

Figure 16 – Transport DLP to PDIM

ii. Install the DLP into the PDIM – New Context

Because the four critical functions are integrated into one system in the new transporter, there is a direct time savings of at least an hour for the PDIM transaction.

Once the system is on the ramp, the TAO will command the system to rotate from horizontal to vertical position and lock it in place. Tritium is sampled. The rear end cap is removed, allowing access to the DLP inside the transporter. Rigging is then installed to the DLP to lift it from the transporter over to the

PDIM, and then lowered into the DIM. The rear end cap is reinstalled on the transporter, and the TAO commands the transporter to rotate back to horizontal from the vertical position (Figure 17).

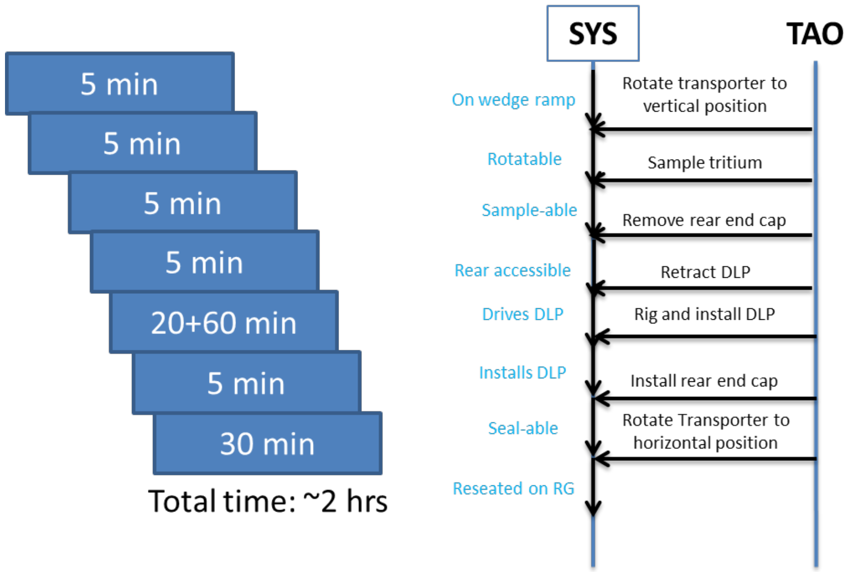

Figure 17 – Install DLP to PDIM

iii. Install the DLP into the EDIM – New Context

As mentioned in Section 2, the "to-be" context will be comprised of a single transporter that contains integrated operations for the four vital functions. By combining the Orange Cart, Running Gear and DHU, the rigging operations that used to take up much of the time have been eliminated, directly yielding a cost savings of at least an hour per rigging exchange.

Once the system is located near the back of the EDIM, tritium is sampled and then the containment portion opened. DPV is attached to the container and turned on to allow negative airflow over the diagnostic, thereby drawing any contamination away from the operators. The system drives the DLP into position behind the DIM. The system performs the fine adjustment, manipulating each of the six degrees of freedom. Once it is aligned, the system drives the DLP into the DIM. The system is driven away from the DIM, DPV disconnected, and caps reinstalled (Figure 18).

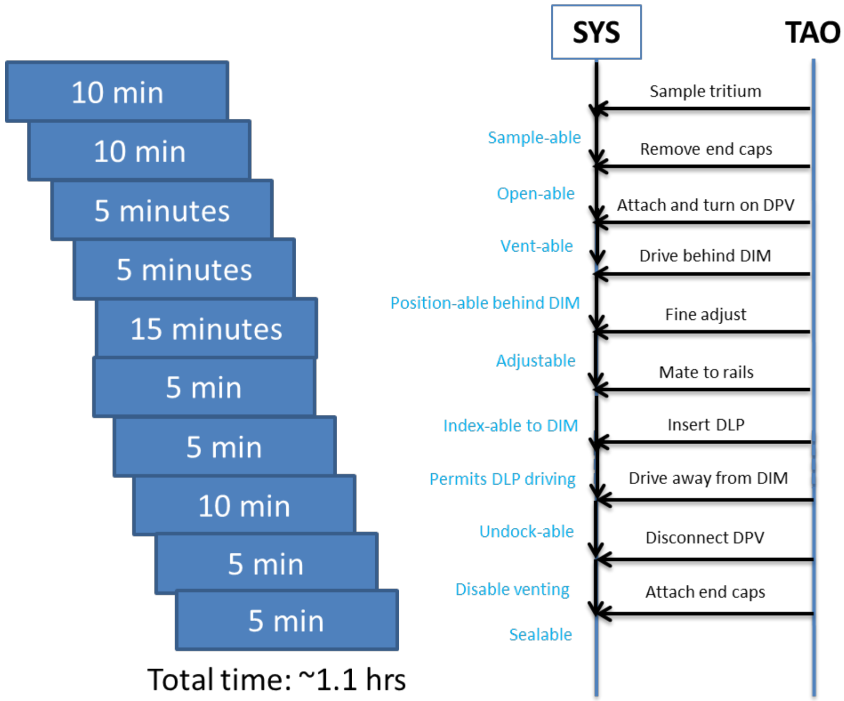

Figure 18 – Install DLP to EDIM

6. Implementation Concepts Selected and Rationale

There are various ways to implement a new transporter system for the DLPs. A new system could be incredibly complex and intelligent, simple and dumb, or any combination of the two. Various concepts were thoroughly considered for each subsystem and directly correlated to their fulfillment of the sacred expectations. Funding and scheduling were also considered, though they are not a part of the sacred expectations. The direction from NIF management is to properly scope and develop the fundamentally best concept independent of funding and schedule, which can be considered at a later date.

The below paragraphs describe each subsystem in great detail (alignment, raise/lower, contamination, etc.) and then the different concepts for each, along with the rationale for the preferred selection.

a. Subsystems

The transport and handling system has four major subsystems – transport, containment, raise/lower alignment and fine adjust alignment. While some subsystems are integrated, each concept must be selected and considered independently.

i. Transport

The transport subsystem is required to move the entire system between buildings, through the facility and from station to station while interfacing with the existing building structure and constraints. Six concepts were identified and are discussed below (Figure 19).

Manual – A manual concept for transport is part of the existing system. This realistically requires multiple operators to guide and push the system through the facility. While the current design is cumbersome and does not meet the expectations, a significantly different new design could allow the manual transport to better adhere to the expectations. When weighing this option against the expectations, it does not appear a manual operation will be simple and easy to use if multiple operators are still required to move and push the system. With the large weight of the system and DLP (~1200 lbs.), safety will not increase if it is still a manual operation. Any significant design change or redesign for a manual transport scheme may only marginally decrease the time it takes to transact a DLP. This feeds into the radiation controls; if the operators are required to touch the system multiple times while taking the same amount of time to maneuver through the facility, this option does not adhere to DOE's principle of ALARA (As Low As Reasonable Achievable) for mitigating worker exposure.

Automated – An automated system would include a method of driving the system through the facility by utilizing a remote, joystick, or application on an iPad. The system would include a motor and battery power, as opposed to gas or electric, to adhere to the cleanliness and materials regulations for the facility. This system would be simple to operate and easy to use, and only require minimal training. It would be safe for operators and would decrease the number of people required to transport it, adhering to ALARA principles. This may slightly decrease the time it takes to transact DLP.

Self-propelled – A self-propelled transport system would include a method of self-driving the system though the facility. It would include a navigation system to drive the transporter through the facility.

This could be implemented through a track system on the floor, painted guidelines on the floor, or utilizing the survey monuments that are already installed throughout the facility. An optical system could be utilized for any of those methods or a laser tracking system for the survey monuments. It would be self-powered through a battery system, as opposed to gas or electric, to adhere to the cleanliness and materials regulations for the facility. This option would be safe for operators, work with the existing facility structure, and potentially decrease the number of required individuals to operate the system, thus meeting ALARA principles. The major drawbacks of this system include extensive training, potential difficulty to use, decreased reliability due to the increased number of parts and intelligent interfaces, and a likely increase in maintenance to keep the system functional. It could also require upgrades to the facility, which could be costly. It also represents a potentially significant expansion in the capabilities of the design team that are not consistent with current resources available at NIF.

Combination of Manual and Self-Propelled – The fourth option is a combination of manual and self-propelled, in other words an assist-type mechanism. This could be similar to a lawn mower system, where the mower drives itself but still requires an operator to steer it. Another option is a hydraulic or air valve to facilitate ease of movement or self-propulsion, while still requiring an operator to guide it by hand. This option would still be simple and easy to use, and it would increase worker safety by improving ergonomics to allow the weight of the system to be driven by the assisting mechanism. It would work with existing facility structures and decrease the time it takes to transact a DLP. It would have potential issues in compliance with radiation protocol if a solution like air-bearings were used that could stir up potential contamination and miscellaneous particulates on the floors and other surfaces.

Vacuum tube – The vacuum tube idea is a revolutionary type of idea that could greatly improve many aspects of the transport and handling operation. The idea would be similar to a bank vacuum tube, where a series of tubes would be installed in the facility, the DLP is loaded into the tube, and a suction system would transport the DLP through the facility to the appropriate location. While the system would be easy to use, safe for operators, an effective method of containment and a great reduction strategy for the time it takes to transact a DLP, it would require extensive upgrades to the facility and would likely be very costly, so this option would be extremely cost prohibitive. It likewise has the potential to seriously and catastrophically damage the DLP, which is a non-starter.

Overhead rail system - an overhead rail system was briefly considered, as this is a similar concept to that which is implemented at the Omega EP facility at the Laboratory for Laser Energetics in Rochester, NY. This concept could be simple and easy to use, allowing a DLP to be connected to a hoist that is attached to a rail system. The DLP would then be guided by an operator through the facility. This would require extensive upgrades to the facility and the transaction between subsystems could greatly increase the time it takes to transact a DLP. This system is time and cost prohibitive.

	Transport System Concepts					
	Manually pushing DLP	Automated driving (joystick/ipad or drivable)	Self-propelled	Combination of manual and self propelled (lawn mower/lift assist arm idea)	PDIM bank vacuum tube idea	Overhead rail system
Time	0	1	2	1	2	0
Easy to use	0	2	0	1	2	0
Safe (ergonomics)	1	1	1	1	0	0
No DLP Damage	2	2	1	2	0	0
Rad Controls	2	1	1	1	1	0
Reliable/Maintainable	0	2	2	1	2	0
Works with Infrastructure	0	1	2	2	2	0
Summation	5	10	9	9	~~9~~	~~0~~

Figure 19 – Pugh Matrix for Transport System Concept Selection

ii. Containment

The containment subsystem is required to house the DLP as it moves throughout the facility while protecting the DLP and containing the contamination. Seven concepts were identified and are discussed below (Figure 21).

DHU/DSU – The DHU and DSU are the containment methods for the existing transport system. The DHU is a 3.5m-long stainless steel tube with ports, valves, and removable spools at each end. The DHU is cumbersome to move around and is considered by many to be overdesigned because it is able to hold vacuum, a capability that has never been used. The DSU is similar to a DHU but does not have easily-removable spools on either end. Both the DHU and DSU must be rigged on and off the Running Gear or Orange Cart for transport. They also interface with the storage garage in the SY2. This current method takes too much time and requires many operators.

DHU – The DHU is the same as above, but this option would require converting the DSUs to DHUs. This is resource intensive and will not be considered.

Hinged-Top Vessel – the hinged-top vessel (Figure 20) would be something lighter in weight than the existing design, with a type of hinged top for access. This could allow for the DLP to be worked on while in the transport container, instead of having to remove them from the containers to a work location. This could also potentially allow the DLP to be installed without lifting the entire storage container.

Figure 20 – Example of a Hinged-Top Vessel (Source: http://www.axispackaging.com.au/re-useable-cases-bins/extendable-cylinder-case/)

Frame structure, open-sided – this concept is a frame-type structure possibly built out of 80/20 or some similar assembly-type structural material rather than being forged or milled out of bulk metal. The sides of this frame structure would be completely open, allowing much access to all areas of the DLP and aiding in ease of use. The design would work with existing facility infrastructure and would be reliable and require minimal maintenance. The greatest downside to this design is that it would provide no protection for the operators from contamination, which is prohibitive.

Frame structure, clear-sided – this concept is similar to the above design but it has a clear siding to the framing, possibly a Plexiglas-type material. The clear sides would allow high visibility of all areas of the DLP, which would aid in alignment, installation, or possible troubleshooting of the DLP. The design would work with existing facility infrastructure and would be reliable, requiring minimal maintenance. The clear sides would provide contamination protection.

Frame structure, metal closed sided – this concept is similar to the above design but it has metal siding instead of clear.

Simplified DHU concept, metallic – this concept is the selected idea, which is a combination of the existing design and the two sealed-frame structure concepts. This idea would still be a tube type containment design, but eliminating the overdesigned "bells and whistles" of the current design. Since the current DHUs were overdesigned, this new concept would allow the contamination container to be much lighter, not be required to hold vacuum, have a reduced number of ports and valves, allow the removable parts to be completely tool-less, and be operable with one person. This design would greatly increase the reliability, reduce maintenance, and still work with existing infrastructure and current and future contamination requirements.

	Containment System Concepts						
	DHU/DSU	DHU	Hinged top vessel/Pelican Case (blue cylindrical case, expandable)	Frame structure, open sided	Frame structure, clear sided	Frame structure, metal closed sided	Simplified DHU concept, metallic fully sided, lighter, no bells and whistles
Time	0	0	1	2	1	1	1
Easy to use	1	1	1	1	1	1	1
Safe (ergonomics)	1	1	1	0	1	1	1
No DLP Damage	0	1	1	2	2	2	2
Rad Controls	2	2	2	2	2	2	2
Reliable/Maintainable	2	2	1	0	2	2	2
Works with Infrastructure	0	0	1	2	1	1	1
Summation	6	7	8	9	10	10	10

Figure 21 – Pugh Matrix for Containment System Concept Selection

iii. Alignment

a. Raise/Lower

Manual hand crank – the manual hand crank is the existing method of operation and does not meet the sacred expectations. It is not simple or easy to use, requires multiple operators, and the number of rotations and the posture of the operators makes the ergonomics unfavorable. This method adds much time to the transaction operation, along with the added time to maintain the drive shaft system since it is increasingly unreliable.

Manual lift-assist – the manual lift-assist would employ a spring-loaded, pneumatic, or hydraulic system, much like the TAS handling arm already used at NIF. This method could consist of something like a spring-loaded lift-assist, a gurney, or a pneumatic strut used to open and close a car trunk hinge. It would apply a force to assist in the raising or lowering of the load, eliminating the repetitious cranking inherent in the existing system and increasing ergonomic safety. This type of system would also reduce maintenance requirements and increase reliability. It would, however, still require manual manipulation.

Tool or drill – the tool example could consist of a drill or tool to attach to the drive mechanism in order to raise or lower the load. This method is not favorable, as it is yet another tool the operators would have to keep track of. It may not reduce the maintenance requirement if the reliability of the drive mechanism does not change. This method would not reduce the transaction time.

Joystick/remote for automatic driving – a joystick or remote idea would require corded or wireless control of the raise and lower mechanism. This would have to work in conjunction with an improved drive mechanism that would facilitate automation of the movement. The remote or joystick would improve ergonomic safety and have a simple enough interface to allow ease of use. The movement would be such that it would not damage the DLP and would allow height adjustment for working with the existing infrastructure.

iPad application through Wi-Fi or Bluetooth – this method utilizes a control application from an iPad and would likely interface with the control system through Wi-Fi or Bluetooth. This is similar to a joystick or remote but would be a more user friendly interface. The iPad would require a sophisticated control system to provide all required control points. The interface would be simple and easy to use, it would be safe for operators, and would be reliable. The implementation would require the system to be safe for the diagnostic while increasing reliability and decreasing maintenance. A single control panel interface in an iPad would reduce the transaction time.

It is important to note here that the PDIM method of operation is significantly different enough from the horizontal position that it requires consideration separately to ensure it is accurately considered (Figure 22).

PDIM, horizontal and vertical integration – the integration of the horizontal and vertical position into a mechanism within a single transporter is important for a new design if it is to be easy to use and increase turnaround time. The transfer from horizontal to vertical would be integrated in the system and would not be separate. This could be accomplished by large rotary bearings gripping the outside of the container and allowing for rotation from horizontal to vertical and back. This method would still allow for the diagnostic to be protected and eliminating separate mechanisms will increase operator safety. This would also increase reliability and decrease required maintenance

PDIM, rigging from horizontal to vertical – this is the existing method of operation. While a rigging operation can be reliable, there is an increased maintenance cost of the rigging equipment. The system was also designed with a high safety factor, but rigging is inherently more risky than non-rigging operations. The rigging requires much training and has many parts, so it is not simple to use. Rigging also inherently adds a significant increase in the duration of the DLP exchange.

PDIM, separate structure to perform rotation – a separate structure was suggested to perform the rotation from horizontal to vertical to eliminate the rigging operation. This could be a stationary structure near the PDIM, eliminating maintenance and increasing reliability. It would be simple for operators to use, with a simple interface (manual or joystick operated) and would require minimal training. It adds time by introducing yet another subsystem interface.

	Alignment System Concepts - Raise/Lower									
						Polar DIM				
Raise/lower method of operation and method of movement	Manual – hand crank	Manual – lift assist (spring loaded, TAS arm)	Tooled – drill example	Joystick/ remote for automatic driving (cabled or not)	iPAD app for driving, bluetooth (or wireless)	PDIM – integrated for horizontal to vertical position	PDIM – rigging from horiz to vert position of the container	PDIM – separate structure to perform rotation (stand, rail system, etc)	PDIM – open top container, rig DLP directly from 50' and change orientation	PDIM – (PTT) pneumatic tube transport
Time	0	1	0	2	2	2	0	1	0	2
Easy to use	0	1	1	2	2	2	1	2	1	2
Safe (ergonomics)	2	2	2	2	2	2	1	2	0	0
No DLP Damage	2	1	2	2	2	2	2	0	2	0
Rad Controls	0	1	1	1	1	2	1	2	1	0
Reliable/Maintainable	1	1	1	1	1	1	1	1	0	2
Works with Infrastructure	0	1	0	1	1	2	0	1	0	2
Summation	5	8	7	11	11	13	6	9	4	8

Figure 22 – Pugh Matrix for Alignment – Raise/Lower System Concept Selection

b. Fine Adjust

Manual – the existing method of fine alignment adjustment is somewhat manual. The DIM is required to be commanded to a load position for the last transaction, but the stepper motors on the DIM bipods may lose steps over time. In addition, the fine alignment of the DHU on the Orange Cart can be manually adjusted through rolling the DHU in the Orange Cart saddles, raising or lowering each Orange Cart separately for pitch, and manually pushing both carts together to the right or left for yaw. Fine adjustment and docking in Z (along the axis of the DIM and DHU) is achieved by manually pushing the load on the linear rail stages on the Orange Carts. Each degree of freedom for fine alignment is cumbersome to operate, not intuitive, and may require several iterations for alignment. This leads to low reliability and difficulty in performing maintenance. As mentioned previously, pushing the Orange Carts is not as ergonomic for the operators as it could be.

Semi-manual, joystick or remote – the selected method for new operation is to be semi-manual fine adjustment of alignment, through an interface such as a joystick, remote or iPad, which was mentioned in the previous section. The operators will have an interface to control the various aspects of the fine adjustment mechanism with simple buttons or control for X, Y, Z, roll, pitch and yaw. Allowing the system to control all aspects of the fine alignment eliminates the need for the DIM to be precisely positioned, increasing reliability of the operation and mechanisms. The control interface will be simple for operators to use and require little training. Controlling fine alignment through the interface will make it safer for operators so they are not required to manually touch the loaded system. The system will be safe for the diagnostic and require little maintenance.

Automatic, with feedback loop – this suggestion would require an active feedback loop to position the system and eliminating much of the operator interaction for alignment. An example would be a laser alignment system working with a survey monument or retro-reflector installed around the facility or in the DIM to provide a feedback loop. The system would automatically iterate between the known position of the DIM and the transporter, which controls the DLP position with the required precision. While this option could increase reliability, be simple for operations, and reduce maintenance and turnaround time, this option would require upgrades to the facility. Though this option scored higher in the matrix, it is considered not a viable option due to potential cost and time to implement. This would require a considerable increase in the available technical personnel resources to design such a system.

Pre-metrologize for fixed position – this option also scored well but was not chosen. It would require substantial engineering work up front to metrologize the facility, DIM, and new system to limit the error to within the tolerance for the system. With such advanced metrology, the system could be pushed or driven to the load position, then commanded to a set point that each time would successfully install the diagnostic. This option could be simple to use, increase reliability, and decrease maintenance while being safe for operators and the diagnostics. When considering past methods of alignment or similar implementations throughout NIF, it is inherently difficult to pre-metrologize or survey out the errors in a system for accurate repeatability every time, so this option was not chosen.

	Alignment System Concepts - Fine Adjustment			
	Manual	Semi-manual – joystick or remote (iPad)	Automatic – retro reflector for laser surveying for alignment, active, feedback loop	Pre-metrologize, survey ahead of time, then go to fixed position (set points)
Time	0	1	2	2
Easy to use	1	1	1	1
Safe (ergonomics)	2	2	2	1
No DLP Damage	2	2	1	1
Rad Controls	2	1	1	1
Reliable/Maintainable	1	1	1	1
Works with Infrastructure	0	1	2	2
Summation	8	9	10	9

Figure 23 – Pugh Matrix for Alignment – Fine Adjustment System Concept Selection

It is interesting to note that the Pugh Matrix method for subsystem selection has certain limitations in this case (Figure 23). Although certain subsystems appear to rank equal to or greater than the selected subsystem concept, the numerical ranking system of 0, 1, and 2 does not always adequately capture the relative strengths and weaknesses of various concepts. For example, a non-starter that violates a basic constraint within NIF would be a given a 0 rather than a negative score that differentiates it from neutral (1). Engineering judgment must therefore be used to eliminate concepts that inherently violate constraints or so drastically compromise a sacred expectation so as to render it unfeasible as a concept.

Summary of Subsystems Selected based on Pugh Matrix Analysis and Domain Knowledge:

- Transport → remote-controlled, user operated
- Raise/lower → remote-controlled, user operated
- Fine/adjustment → remote-controlled, user operated (could consider phased implementation to automatically align)
- Containment → optimized “DHU-like” container with ample access ports

7. Proposed System Operational Architecture

In contrast to the disjointed series of subsystems in the current process for transporting and handling of the DLPs, the new system (Figure 24) features a single transporter with the contamination container integrated into the transport cart. This eliminates all major forms of rigging required and minimizes the subsystem exchanges, thereby dramatically improving operational efficiency.

In order to improve operator ease of use and ergonomics, the transport will be fully operable via a handheld controller capable of transmitting user commands to the onboard processor of the transporter. The basic executable functions vital to operations are 1) drive the transporter through the facility, 2) raise and lower the container, 3) provide 6 DOF fine adjustment of the DLP, and 4) rotation of the DLP into a vertical orientation to be installed into Polar DIM.

The new concept provides greater operational flexibility by having an adaptable footprint in X, Y, and Z. At its lowest position, the transporter and container will be capable of rolling under TAxPOS in the NIF Target Bay. It will be able to raise to other positions in order to dock with the alignment stand and the EDIMs. The system will also raise sufficiently high in order to allow for DLP rotation into a vertical position that can interface with the Level 6 platform at the back of Polar DIM. All of these motions are commanded from the user-operated controller. As the Center of Gravity (CG) changes, a series of stabilizing supports will expand as needed to provide the requisite footprint to comply with the design safety standards for stability and seismic restraint.

In contrast with the current system, the new system will also absorb the dynamic shock loads imparted to the system while it moves through the facility and crosses numerous thresholds and minor surface changes. Rather than reusing the DHU, the new containers will be optimized for access, weight, and handling rather than being overdesigned for holding vacuum. This requirement has been rendered obsolete from the original DHU design document as a function of more experience in the operational scenarios. The overall system will also feature an optional onboard nitrogen (N_2) backfill system that can be connected to the front face of the airbox to protect the micro-channel plates (MCPs). These critical optical components of the DLPs are sensitive to moisture and will delaminate with prolonged exposure to room air. Depending on budgetary constraints, the container may be required to be separable form the transporter cart and stored in a different location. It is the strong recommendation of the design to keep the container integral to the cart, and use the entire stowed transporter as the storage system.

There will be limited impact to the NIF facility in order to accommodate this new system. As mentioned above, the area used for storage of the container and its transport will likely be the same as currently used (SY2, Level -2). However, there may be some minor infrastructure changes required if the containers must be stored separately from the transport cart itself. The design team has the strong preference to eliminate separate storage from the transport cart, and instead, the container should be stored integrally with the transport cart. This will require a capital investment consistent with the quantity of diagnostics to be fielded at NIF.

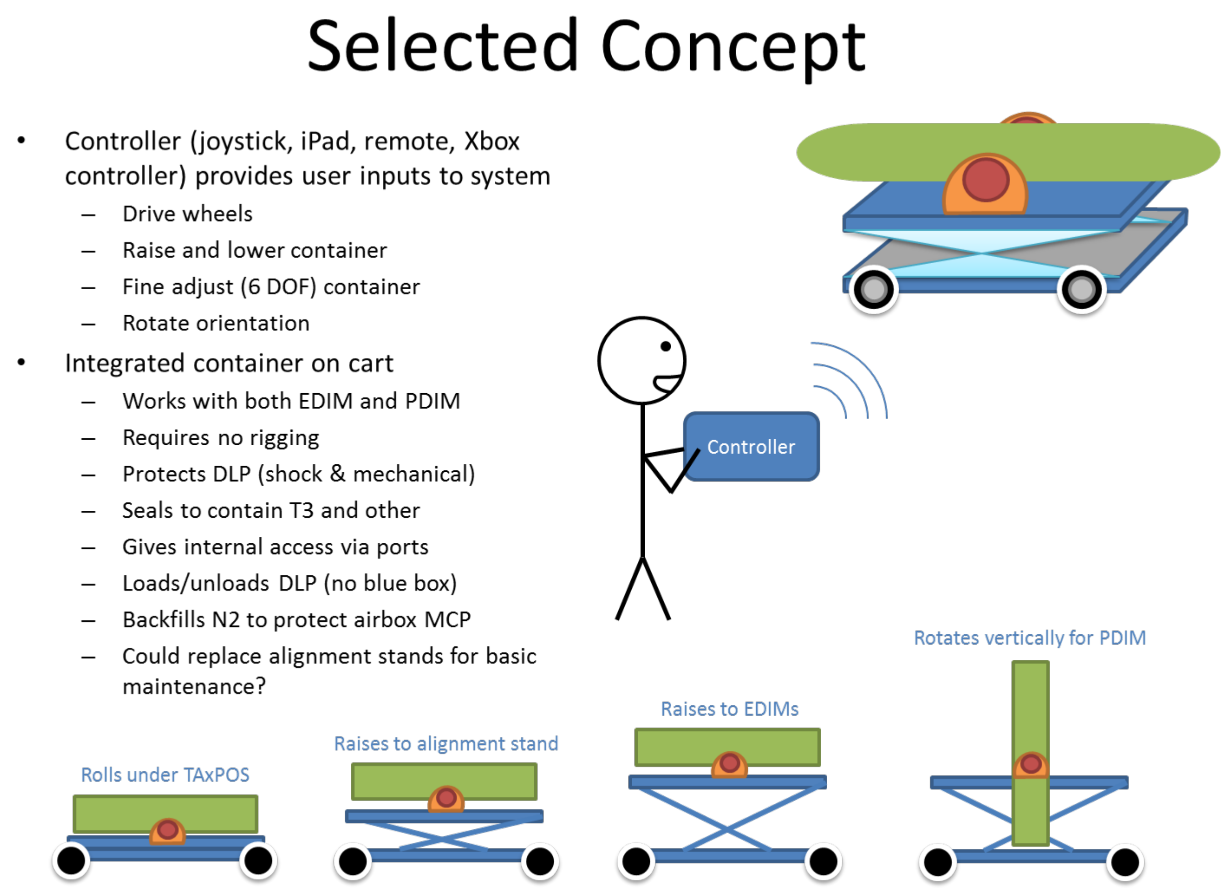

Figure 24 – Concept Diagram for New DLP T&H System

To better conceptualize the new T&H system, the physical (hardware-centric) and functional (action verb-centric) architectures are discussed below.

Physical Architecture

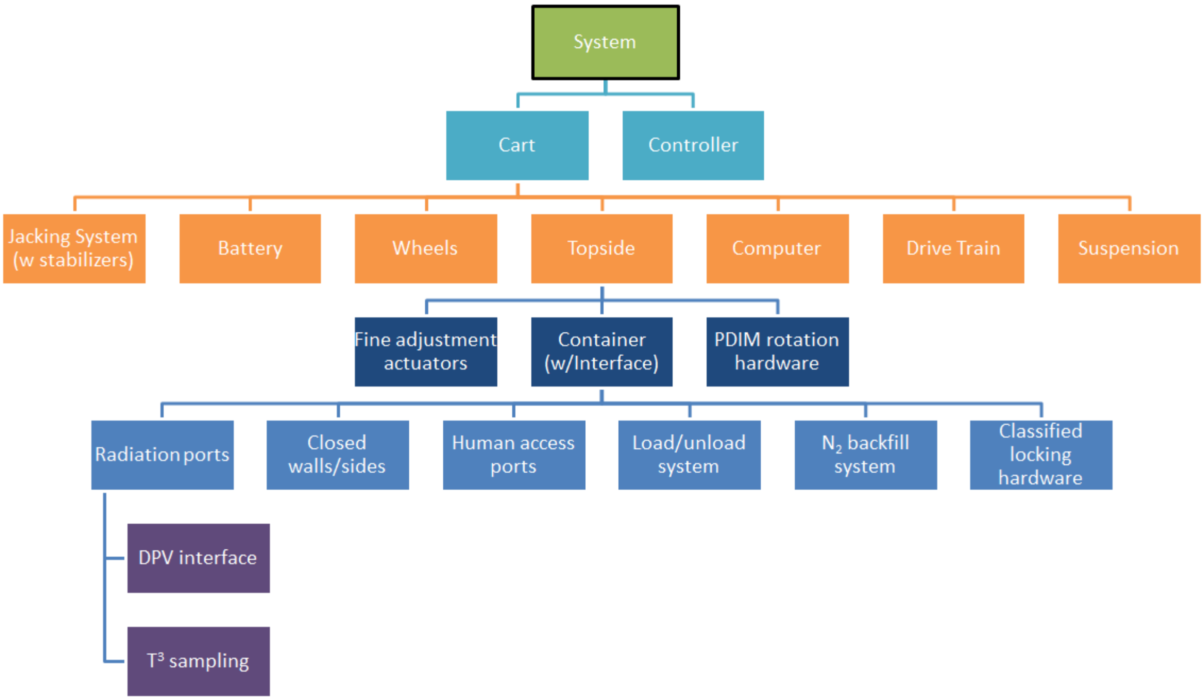

Figure 25 – Physical Architecture for New DLP T&H System

At the highest level, the new DLP T&H system is physically comprised of a transporter cart and the user-operated controller (Figure 25). The transport cart itself has a series of subsystems that provide all of the functions described in the functional architecture below. The carts primary subsystems are the jacking system for raising and lowering the cart, the battery to provide overall system power, the wheels to roll the cart, the onboard computer to process signals from the controller, the drive train to connect the drive motors with the actuation mechanisms, the suspension to dampen the dynamic shock loads, and the topside. In borrowing the concept from the offshore oil and gas industry, the topside can be viewed as the system of components that interfaces with the container and gives fine adjustment plus vertical rotation. If designed properly, the topside may theoretically be decoupled from the lower portion of the transporter cart such that a new interface could be installed to be compatible with the long-term vision of completely new DIMs and new DLPs. The lower portion of the cart wouldn't need to be redesign since it provides the basic capabilities of transport through the facility and raising and lowering the load. However, the container and topside actuation mechanisms for fine adjustment and vertical rotation may need to be reconsidered, modified, or abandoned depending upon the design of new DLPs.

At this stage in the project development, the container is the only topside component that has been scoped with any significant detail since it was consistently stressed by stakeholders as a subsystem needing improvement and optimization over the existing DHU. The new container features:

- Ports for radiation sampling and DPV connections,
- Fully sealable sides,
- Access ports sufficiently big and conveniently located for people to interface with the inside of the vessel or the DLP directly,
- A load/unload drive system that powers the DLP into or out of the container rather than having to hook-up an external power supply (currently the "blue box"),
- Manually connected dry nitrogen backfill system that automatically regulates the pressure within the front-flange cavity covering the moisture-sensitive airbox MCP, and
- Locking features on all ports to protect physically secured DLPs, in case Classified Operations desires this functionality in the future.

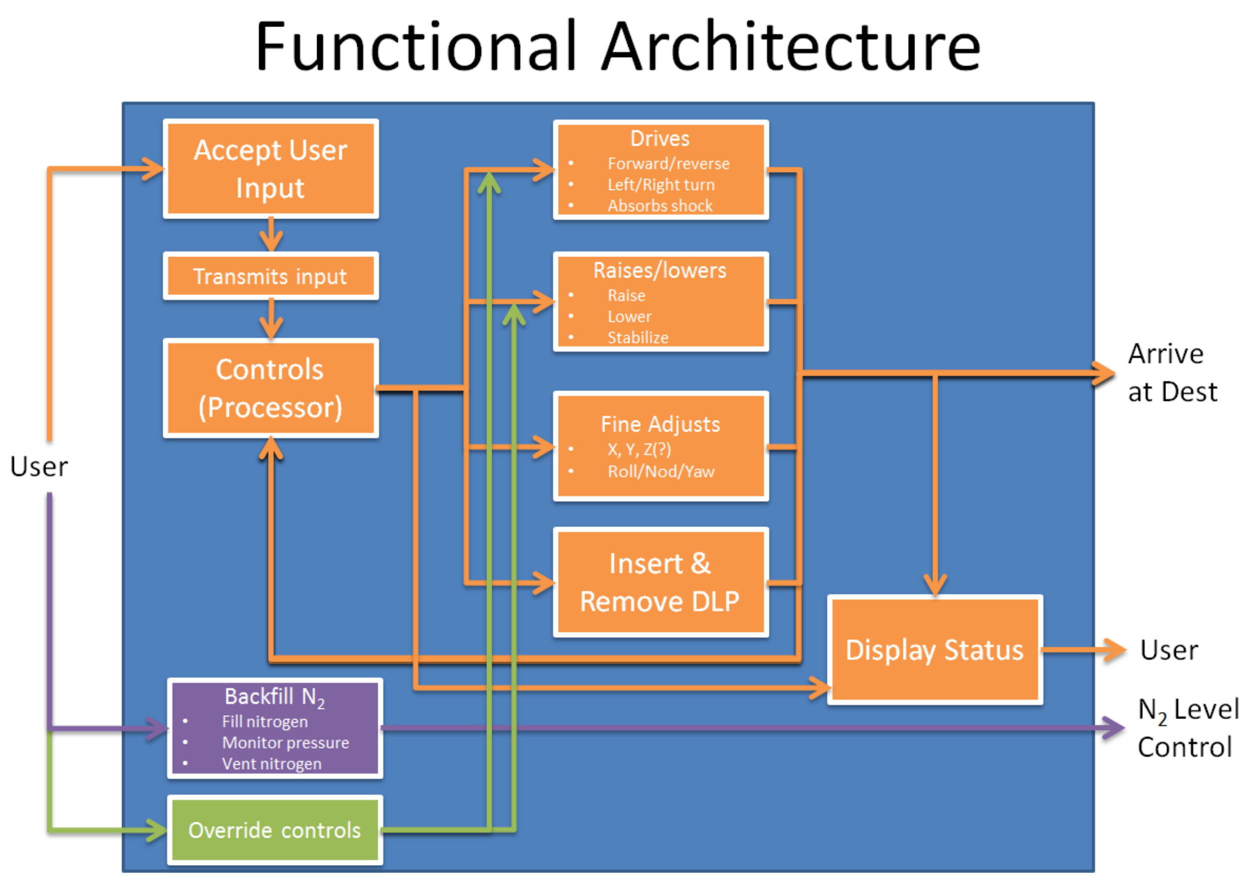

Figure 26 – Functional Architecture for New DLP T&H System

An alternate way of viewing the new system is through the lens of a functional architecture (Figure 26), which employs an approach centered on the "action verbs" that the system must perform. References to actual hardware are neglected in deference to capabilities and basic functionality that the system must provide.

The new DLP T&H system is entirely user-driven, and as such, the primary function the system must perform is to accept the user input. Once accepted and transmitted to the transport cart, the requested action is processed and actions are commanded of the transporter system to drive through the facility, raise/lower the load, fine adjust the load, or insert/retract the DLP. Within each of these high-level functions, there are likely several sub-actions that must be possible, but the full scoping has not be undertaken within this document. All of these actions result in confirmation back to the user via a display screen that the transporter has executed the command and arrived at the commanded location.

In addition to the controller inputs, the system will be expected to handle the manual connection of the N2 backfill system. The intent of this backfill system is to supply and maintain the nitrogen pressure to fill the airbox front flange cap, monitor the pressure, and vent when desired. A second important manual input is to be able to override the controls system to restore the system to a “safe” state that can be moved out of the way. In the event of an off-normal failure, the operator would disable the controls system, safely lower the load, and roll the transporter out of the way so that the critical path shot cycle can continue without needing to fix the transporter in the Target Bay.

8. System Requirements

In drafting the system requirements, the input and suggestions from the stakeholders were considered, along with the design requirements for the selected concept. The sacred expectations first and foremost are prevalent throughout the system requirements (Table 1). Where an expectation was articulated as a characteristic and not originally quantifiable, the expectation was dissected (using QFD) in order to identify tangible requirements. Constraints in the form of requirements, along with NIF design standards, were also included. Some requirements do not yet have precise numerical values and will have to be added at a later date after design, analysis, and prototyping is undertaken.

Flow-down requirements are explicitly NOT developed in this document in order to keep consistency with NIF design practices. They will be developed after formal acceptance of this project into the work scope and detailed design begins. Particular emphasis must be placed on developing the flow-down requirements in accordance with their importance scores, the highest of which are highlighted in yellow in the QFD below (Figure 27).

QFD	Priority	Footprint (length, width, height)	Weight	Motor Performance, drive train characteristics	Wheels (size, OD, materials, Etc)	Controller Performance (response, complexity, accuracy, latency)	Tools (number, size, type, etc)	Number of subsystem handoffs, exchanges, int	Number of operators	Vacuum Utilities (DPV, T3, N2) and (types and qty of ports, flow rate, connection)	Number of parts	Materials	MTBF (drive train, electronics)
Time	4	1	3	9	3	9	3	9	9	3	1	0	9
Easy to use	7	3	3	3	9	9	3	9	9	3	3	1	0
Safe (ergonomics)	5	1	3	1	1	9	3	3	0	1	0	1	0
No DLP Damage	3	0	1	3	9	1	0	1	0	1	0	1	0
Rad Controls	1	0	0	1	1	1	1	1	1	9	1	3	0
Reliable/Maintainable	6	1	0	9	3	9	3	3	0	3	9	9	9
Works with Infrastructure	2	9	1	1	3	1	1	9	0	3	0	1	3
SUM		54	53	128	132	204	69	154	100	74	80	74	96

Legend	**H = 9 M = 3 L = 1** **No Correlation = 0**

Figure 27 – QFD Matrix to Correlate System Characteristics with Sacred Expectations

Table 1 – Top-Level System Requirements

#	Requirement	Requirement Rationale	Verification Method (Design, Test, Inspection, Analysis)	Stakeholder Expectation (Section 2, unless stated)
1	The system shall be capable of transporting a contaminated DLP through the NIF facility for installation in/removal from DIM 90-78, DIM 90-315, and PDIM (DIM 0-0).	basic function	D, I	f.7, f.8, g.4, g.6, g.7
2	The system shall be capable of transporting a DLP from the OSB refurbishment labs to a DIM without a subsystem exchange.	Eliminate 2 rigging operations	D, I	f.4, f.5, g.7
3	The system shall be able to 1) rotate the DLP from horizontal to vertical orientation, 2) safely support, stabilize, and lock the load in the vertical position, and 3) dock with the 62' platform at Polar DIM.	May not need to physically dock with 62' platform but rather just interface	D, T, I	f.4, f.5, f.6, f.8, f.10, g.1, g.7
4	The system shall require only one operator to operate.	goal should be single operator	D, I	f.4, f.5, f.6, f.9, g.1, g.2
5	The system shall adhere to NIF radiation control standards.	constraint for design at NIF	D, T	f.7, g.6

#	Requirement	Requirement Rationale	Verification Method (Design, Test, Inspection, Analysis)	Stakeholder Expectation (Section 2, unless stated)
6	The system shall have a MTBF of 10 years.	If there are 10 carts, this could represent a failure of one per year; need maintenance plan, this system would be a failure if there was no maintenance plan	D, T, A	f.8, g.5
7	The system shall work with the existing infrastructure of NIF.	EDIM, PDIM, TBL2, TBL5, elevator, SY, OSB, alignment stand, GDE, HMMA, existing vehicular transport from B391 to B581, travel under TARPOS and TASPOS, etc.	D, T, I	f.2, g.4
8	The system shall have a limited number of tools required for operation.		D, T	f.7, f.9, g.1, g.2, g.7
9	All tools required for the operation of the system shall be integrated into the system.	All tools shall stay with the system, do not go so search for a tool in the tool crib, etc.	D	f.7, f.9, g.1, g.2, g.7
10	The system shall be designed to minimize the quantity and duration of top level system exchanges.	Minimize the number of rigging operations, number of carts and systems used to transport (BC, OC, RG, etc.)	D, T	f.4, f.5, f.9, g.1, g.7
11	The system shall use the raise/lower adjustment to achieve vertical fine adjustment.	Different speeds for coarse vs fine adjust, fewer motors increases reliability, reduces maintenance and complexity	D, T	f.3, f.10, g.1, g.7
12	The system shall accept user input via a control interface.	Control interface must accept input	D, T, I	f.10

#	Requirement	Requirement Rationale	Verification Method (Design, Test, Inspection, Analysis)	Stakeholder Expectation (Section 2, unless stated)
13	The system shall transmit the user input from the control interface to the system.	System must receive input over not yet selected method (Bluetooth, Wi-Fi, etc.)	D, T	f.10
14	The system shall absorb shock loadings up to XXX.	Protect diagnostic from damage	D	f.1, g.2
15	The system shall raise and lower the load of at least XXX lbs.	DLP load requirements	D, T	f.2, f.4, f.5, f.8, f.10
16	The system shall provide fine adjustment capability for all 6 DOFs (X, Y, Z, Roll, Nod, and Yaw).	needed to install DLP	D, T	f.3, f.10
17	The system shall insert and remove the DLP into the DIM.	Eliminate use of blue box	D, T	f.2, f.4, f.5, f.7, f.8, f.10
18	The system shall include a hardware controller to interface remotely with the cart.	no cords preferable	D, T	f.10
19	The system footprint shall expand to meet the most stringent seismic stability requirements.	safety requirement; operationally better if only one position possible	D	f.2
20	The system shall be designed per the LLNL design specifications described in the Engineering Design Safety Standards.	constraint for design at NIF	D	Section 4, point 8
21	The containment vessel shall be integral to the cart to allow for efficient DLP storage.	Not two separable pieces so container cannot be stored somewhere else	D	f.5, f.7, g.1, g.6, g.7

#	Requirement	Requirement Rationale	Verification Method (Design, Test, Inspection, Analysis)	Stakeholder Expectation (Section 2, unless stated)
22	The system shall provide the airbox with dry nitrogen and regulate the pressure level.	micro-channel plate protection for prolonged storage	D	g.3
23	The system shall be able to be overridden to manually lower and drive the system.	Useful for off-normal situations in which, for example, the transporter experiences a failure requiring maintenance, but it is broken behind the DIM and holding up the shot schedule.	D, T	g.1, g.7

9. Organizational and Business Impact

The replacement of the current DLP T&H system with the proposed concept detailed in Section 7 realizes obvious immediate benefits in terms of the resources required to transact a DLP and the ergonomics, safety, and ease of use for the operators. The overall impact to the facility, its staff, and work processes is summarized below:

- Revisions are required to a number of documents to capture the impact of the new system. T&H operating procedures would be significantly rewritten to describe the interfacing of the system with the facility and the sequence required for safe operation.
- A new engineering design note or safety note will be required to capture the basis for the design for normal operating conditions and rare events (seismic, motor stall loads, etc.). The analysis will also include any pressure safety issues or other significant operational hazards.
- An FMEA will be required for the new system to identify as many hazards as possible and define a mitigation strategy for the risk.
- Significant effort will be required to develop new mechanical and electrical drawings packages for the system.
- The system RSE will need to develop, plan, and implement the appropriate level of training to tech the TAO and TDF technicians.
- With sufficient training of the operators, the immediate benefits of the system will allow the Work Center Supervisor and Planner to schedule DLP transactions more frequently and with fewer operators, not only enabling a potentially reduced shot cycle but leaner operations

The maintenance of the system would be captured in a comprehensive maintenance plan document that would highlight the scope, frequency, and expected duration of the preventative work required to keep the system functioning optimally. This would be seen as a significant improvement over the current system and a new model for documentation for complicated engineering systems at NIF.

Note that the above impact is thoroughly tracked, along with key documentation and processes identified, in the standard NIF Integrated Product Review Board (IPRB) and Work Authorization Process (WAP). This is a mandatory process, and anything not explicitly stated above will be captured there. This is also the vehicle by which changes to the legacy doctrine are communicated to stakeholders, especially through design reviews and the subsequent assignment of action items.

10. Risks and Technology Readiness Assessment

As with any new system or technology, there are risks. For the new transporter system to be as successful as possible, it is important to adequately consider the risks ahead of time and to design the system to mitigate those risks. During the execution of this design, the project team is encouraged to drive the risk out of the system as a function of project lifetime. This requires active and iterative evaluation and resolution of the biggest risk items that will prevent the project for making progress. As risk is removed in one area of the project, a new risk will arise as the next one worth tackling.

The most significant areas of risk in the design of the new DLP transporter system are:

- Managerial Commitment – senior NIF engineering and operations management must agree to the scope of the project, accepted it into the work plan, and commit to launching and implementing a design effort. Bottom-up coalition agreements to the utility of the upgrade plus well-constructed arguments grounded in sound logic and operator buy-in will facilitate this process.
- Resources – the dynamic environment of NIF means that programmatic priorities may change as required to accomplish the most important objectives. This can lead to staffing and monetary constraints that cause project execution starts and stops. Documentation of "why" design decisions are made is a crucial mitigation strategy for managing this risk.
- Design Team Technical Competencies – once the concept is developed and each subsystem mechanism is defined more clearly, the project lead must clearly define the core technical competencies required in the design team members to successfully design and field the transporter.
- Procurement Cost – although senior NIF engineering management expressly requested that cost not be considered in the development and scoping of the best solution based on the systems engineering process, the funding to build new DLP transporters will need to come from some channel. Rather than fabricating the entire production quantity of transporters (15-20) through LLNL, it is recommended that the design team be responsible for the prototype development, testing, and optimization prior to procurement of the final units. This will also allow operators a chance to utilize the new hardware system and suggest areas for improvement.
- Design – one mitigation strategy proposed by certain stakeholders is to subcontract the design of the new transporter system to an offsite company that specializes in transporters. Although this may work in theory, the practicality of designing for the uniquely-constrained and dynamic environment of NIF introduces significantly more risk to the project duration, cost, and quality by subcontracting the design. The domain knowledge required to merge so many functions is best accomplished by an in-house, NIF-knowledgeable design team.
- Technologies – the technologies to be employed are well understood and likely commercially available as components if not already as subsystems.
- Operations – to ensure the new transporter system eliminates operational risk, decreases transaction time, increases reliability, and is accepted by the operations staff, the system

concept must be thoroughly vetted with the operations staff. Multiple walk-throughs should be performed to consider all possible, risky operational scenarios and to potentially uncover anything that was not thought of ahead of time.

While some risks are tangible and can easily be designed out or mitigated, others are more intangible, conceptual, or subjective based on the stakeholders. These intangible risks should still be noted here and considered through the actual design and implementation of the new DLP transporter.

1. Is this system being overburdened by integrating too many subsystems? Have all potential drawbacks been considered due to the integration and elimination of the subsystem exchanges?
2. Is the selected concept a truly revolutionary design, or is it still an evolutionary design?
3. How well will the operators take to a new system? There must be a foolproof plan with training, feedback loop, and accountability.
4. To what extent should the design team employ commercial off-the-shelf (COTS) parts rather than custom-designing? Vendors for unique COTS may discontinue a line of parts critical to the operation of the system, but designing custom in-house solutions will increase the cost.

11. Appendix

Glossary of Terms and Acronyms

ALARA – “As Low As Reasonable Achievable”; Department of Energy principle for mitigating worker exposure to radioactivity and radiological contamination

Blue box – surrogate stepper motor driver used to provide motor power to the DLP for insertion and retraction into and out of a DHU or DIM

Blue Cart – single transport cart used to raise, lower, and transport uncontaminated DLPs to NIF

CCB5 – Control Change Board, Level 5; an internal group responsible for a specific sub-function or sub-group at NIF; the group’s approval is required before a significant change is made to the sub-function or sub-group

CZ – contamination zone; area in which possible contamination may be present; has strictest rad controls to prevent spread of contamination to unwanted areas

DHU – Diagnostic Handling Unit; 4m-long sealable container with removal end caps that forms the mobile tritium barrier around a contaminated DLP; DHUs are transported on Orange Carts and Running Gear through the facility

DIM – Diagnostic Instrument Manipulator; 6m-long vacuum vessel system with dual telescoping stages capable of inserting, aligning, and operating a DLP in the NIF Target Chamber to collect data from a shot; DLPs are installed in and removed from DIMs by the TAO technicians

DLP – Diagnostic Load Package; the interchangeable, DIM-based diagnostic instrument and its support hardware mounted to the generic DIM Z2 cart with drive unit and limit switches. Upon being used in the Target Chamber for an experiment, the DLP is considered potentially contaminated. Once removed from a DIM, the DLP must be transported through the facility in a mobile tritium container and transport mechanism.

DOF – degree of freedom; in terms of motion, one of three translational (X, Y, or Z) or three rotational (X, Y, or Z) unique lines of action relative to specified Cartesian coordinate system

DPV – Diagnostic Positioner Ventilation; existing NIF vacuum system for ventilating a contaminated system to the appropriate treatment facility for tritium processing

DSU – Diagnostic Storage Unit; sealable container used only to store contaminated DLPs, thereby allowing DHUs to be used for handling

EDIM – Equatorial DIM; either DIM 90-78 or DIM 90-315, which denote port locations on the NIF Target Chamber

IPT – Integrated Project Team; an inter-disciplinary, cross-functional team with domain knowledge about a group of systems or process; useful for scoping and solving problems across management chains; the IPT oversees some level of operation or change control for the system or group

MCP – micro-channel plate; expensive and sensitive optical component of a diagnostic that will fail with prolonged exposure to moisture

NIF – National Ignition Facility; world's largest and most energetic laser facility for performing fusion experiments capable of achieving net energy gain from fusion (ignition)

Orange Cart – DHU transport cart used to raise and lower the load plus dock with EDIMs; composed of two COTS carts bolted together

PDIM – Polar DIM; also known as DIM 0-0 or Polar DIM

Polar DIM – see PDIM

QFD – Quality Function Deployment; graphical tool to translate user expectations into functional categories; useful for concept down-selection and requirements generation in systems engineering

RCT – Radiological Control Technician; technician responsible for making sure job teams adhere to strict radiological guidelines for safe operation; performs surveys and decontamination efforts of contaminated equipment in order to enable free- or conditional-release to other areas of NIF or offsite

RS – Responsible Scientist; scientist in charge of scheduling and ensuring a given diagnostic is setup correctly for a shot to obtain the desired data

RSE – Responsible System Engineer; single point-of-contact engineering and operations owner of a NIF subsystem; i.e. DIM RSE or DIM T&H RSE

Running Gear – reduced-footprint transport cart with soft, inflatable tires used to transport DHUs to all DIMs

SY – Switch Yard; one of two areas in NIF immediately adjacent to the Target Bay where the NIF beams are redirected from the Laser Bay towards the Target Bay; on one level of SY2, there is a storage area currently designated for DIM T&H equipment

T&H – transport and handling

TAO – Target Area Operators; technician that transports and exchanges DLPs during the NIF shot cycle; contrasts the TDF technicians

Target Bay – the room immediately surrounding the NIF Target Chamber

Target Chamber – 6m-radius sealed vacuum chamber in which the NIF laser beams interact with targets to carry out experiments; diagnostics and various Positioners attach directly to the exterior ports to perform alignment, operation, and data collection functions

TARPOS – Target Positioner; insertable vacuum vessel system capable of inserting, aligning, and operating the target for a shot

TASPOS – Target Alignment Sensor Positioner; insertable vacuum vessel system capable of inserting, aligning, and operating the Target Alignment Sensor (TAS) in the Target Chamber before a shot

TAxPOS – generic description for either TARPOS or TASPOS Positioners

TD/TDE – Target Diagnostics/Target Diagnostics Engineering; organization responsible for the design, engineering, operation, and maintenance of diagnostics in NIF

TDF – Target Diagnostic Factory; organization responsible for refurbishment of DLPs offline between shots